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MEASURES OF ABUNDANCE OF PELAGIC FISH

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Measures of Abundance of Certain Pelagic Fish in Some South-Eastern Australian Waters

By

M. Blackburn and J. A. Tubb

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FACTORS IN THE BEHAVIOUR OF PELAGIC FISH SHOALS IN SOUTH AUSTRALIA AND NEW SOUTH WALES, by Keith Sheard 72

FOREWORD

In the early years of general fisheries survey work in a relatively large area it is inevitable that, in the search for information, a deal of scattered as well as more systematic observations should be collected through the various agencies available. It is of considerable value, as has been done in the following work, to sift out, assort, correlate, and evaluate the results of these observations, to draw or hint at justifiable conclusions, and to set up, in some instances, hypotheses for further testing.

Australia has for several years been seeking information from many sources and through much experimentation on the types and quantities of pelagic (or upper-water dwelling) fishes in the seas around her coasts, with the object of utilizing such resources as might be revealed.

In this paper previous records of pelagic fish occurrences have been reviewed, and account has been taken of evidence forthcoming from aerial reconnaissance, activity of diving birds, observations made from the shore, and in fish markets, surveys by various types of fishing and other craft, catches actually made by surface nets and other gear, the distribution of eggs and larvæ of pelagic fish in the sea, and even the occurrence of the smaller pelagic fish in the stomachs of larger fish. Special emphasis has very naturally been laid on quantitative data where these were available.

The importance of making biological observations concurrently with the prosecution, in the physical sense, of fishery surveys and fishing tests cannot be said to be generally recognized, but it is well exemplified in these pages. In effect, there cannot be depicted a set pattern of fish distribution, nor does the sea "teem" uniformly with fish. Nature rings the changes almost *ad infinitum*. The short accompanying paper at the end of this bulletin shows how the food of the fish can vary in nature, quantity, and depth, so influencing the movements of pelagic fish.

Reference is made in the main paper to the fluctuations in density of fish stocks caused by the fate of the spawn in successive spawning seasons. The movements of sea currents affect those of pelagic fish, probably never twice in exactly the same way. And it is shown to be possible, in some cases, to distinguish sub-sections of stocks of the same fish species, e.g., pilchards, each with recognizable geographical boundaries. Growth rates of fishes also vary, and are important. All these matters must be taken into consideration by those planning to enter the pelagic fishery on the commercial scale, and to them, as well as to those who will prosecute further investigations, this paper should prove of value.

HAROLD THOMPSON
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SUMMARY

1. An attempt is made to indicate the general levels of abundance, at the principal seasons of the year, of the most important non-scombroid pelagic fish in certain waters of south-eastern Australia; and to demonstrate the stability or otherwise of these levels from year to year. This work is mainly intended for the information and general encouragement of those who may be interested in exploiting these species, few of which are adequately used at present. It is based upon the results of the boat survey work of the Division of Fisheries, C.S.I.R.O., and various collaborators since 1938, some records provided by fisheries inspectors over a number of years, and certain information from other sources.

2. The areas for which fairly full information is available are the waters of the north and south coasts of New South Wales, and north-eastern and south-eastern Tasmania. Each has a somewhat characteristic pelagic fish fauna. The species dealt with in respect of these areas are the pilchard, Australian "salmon", horse-mackerel, sprat, and anchovy; and also, in respect of one area, the sea garfish and kingfish (*Seriola*). No satisfactory quantitative data are available in respect of the waters of the Queensland south coast, Victoria, the north and west Tasmanian coasts, and eastern South Australia, although a summary of existing knowledge of these species is presented for each of these areas.

3. The quantitative data refer to occurrence of surface shoals sighted, in default of any better information. Arising from a general discussion on natural fluctuations in fish supply, it is shown that the indices established from such data actually do not necessarily refer to real abundance of fish in an area, but to their availability at the surface there; the two are in some cases not directly related but in others they are, e.g., the pilchard of the New South Wales south coast. Nevertheless these indices of availability represent abundance for the practical purposes of the fishing crews seeking to exploit these stocks by surface nets set around shoals.

4. It was found that the abundance of pilchard shoals fluctuated considerably from year to year on the New South Wales south coast, over a period at which it was fairly stable on the north coast. These fluctuations were due to differing brood-survival effects in earlier years; this indicates the possibility of setting up a system for forecasting such changes if a fishery develops. Pilchard shoals are commoner in the daytime in the winter, but in the warmer months they occur at least as frequently by night. Shoals of horse-mackerel, which seems to be more characteristic of the southern Tasmanian region than any other, occurred at a stable and moderate level of abundance there over a number of years, but failed to appear as plentifully in 1946 because of bad weather, which is a critical factor in determining their availability at the surface. Australian "salmon" are mainly confined to a zone very close inshore, so that the full importance of the species can be better understood from the records of coastal stations than from those of boat surveys

of the general shelf waters. The sprat is restricted to Tasmania and is probably more plentiful in the southernmost waters there. Anchovies occur in all these waters, but less conspicuously outside the bays and estuaries.

5. The attempts which have been made to develop fisheries upon these species, or to extend those which exist already, are summarized, and some tentative conclusions are drawn as to the lines along which success can most probably be achieved in future. Pilchards and anchovies are of considerable potential importance as live-bait for tuna fishing, and for this purpose the most satisfactory means of capture will probably be lamparas or small ring-nets or purse-seines, which could be worked in the more sheltered waters, especially at night. These species are also suitable for canning, for which pilchards in particular could probably be obtained by other means, especially by drift-netting. Horse-mackerel can be captured in fair quantities by purse-seine in Tasmanian and New South Wales waters. Sprats have been caught fairly regularly in small quantities by lampara net, but the available quantities do not indicate good prospects for a fishery based on this species alone. The fisheries for Australian "salmon", kingfish, and sea garfish are probably at or near the limits of the production that can be expected from the beach seines and other inshore gear at present in use, and further large increases will depend upon the development of large surface seines suitable for taking the shoals that occur a little further offshore.

6. In a separate paper under this cover the point is made that the presence or absence of pelagic fish at the surface is largely determined by the kind of plankton available to them or their prey for food from time to time. The greater the proportion of permanent plankton organisms in the total plankton the greater will tend to be the concentration of fish in the upper water layers; whereas where the proportion of temporary plankton organisms is the larger, the fish will tend to seek these at the bottom levels where they originate. Different Australian waters can be more or less characterized on this basis, but there may be important variations in the same region over a period of years.

MEASURES OF ABUNDANCE OF CERTAIN PELAGIC FISH IN SOME SOUTH-EASTERN AUSTRALIAN WATERS*

By Maurice Blackburn, M.Sc., and J. A. Tubb, M.Sc.

I. Introduction

This paper is a detailed progress statement on the quantitative aspects of the geographical and seasonal distribution of certain important pelagic (surface) fishes, especially those not yet exploited commercially, in some waters of south-eastern Australia. Some descriptive matter on pelagic fish has also been included.

The Organization's programme of systematic sea-going survey work upon pelagic fish in these waters began in May 1938, and the data herein recorded include four years' observations in some areas and nearly seven years' observations in another area.

In the Organization's earlier publications on pelagic fish abundance, the terms "moderate abundance", "reasonable abundance", &c., have been used, but in the present paper statements of a more objective character have been made. The findings here presented indicate clearly that, at least from the standpoint of abundance of fish in the sea, the prospects for certain pelagic fishery developments are by no means unattractive; and it is hoped that this may induce those who are in a position to do so to attempt to overcome the technical difficulties involved.

This study contains only passing references to the tunas, an important pelagic fish group which is being treated separately. The position is similar for the barracouta, the other principal scombroid fish of these waters. The present report, therefore, deals with the non-scombroid fishes, i.e. the non-mackerel-like fishes.

II. Sources of Data and Methods and Limitations of the Study

There are two possible sources of data in such a study:

(i) records of quantities caught, which, to be of real value, require to be accompanied by such other information as would permit their expression in terms of catch per unit of fishing effort, or some similar index; and

(ii) records of occurrences directly viewed as shoals at the surface of the sea, by observers in boats, in aircraft, or on the shore; to be of real value these should be accompanied by such other information as would permit their expression in terms of shoals seen per unit period of observation, or some equivalent.

The first line of approach (i) is the one usually adopted in studies of fish abundance. It is frequently the only one possible, since the alternative, (ii), is only applicable to (some) pelagic fish. Moreover, the quantity index in this instance is usually more reliable than that available from records of type (ii),

* Typescript received September 24, 1948.

because the catch is nearly always precisely measurable. Furthermore, this second approach cannot be used to measure total fish abundance unless there is a constant relationship between this and the abundance in the surface shoals; however, as indicated later, this is not always so.

For this study, records of the first type were not available, and so those of the second type were used. Of the species discussed here in detail, only one, the Australian "salmon", supports a fishery of any great importance, and only two others, the kingfish and sea garfish, are the subjects of fishing operations of any regularity and significance;* and while some records of total catch are available for these species, there is no information for computing reliable catch-per-unit-effort indices. Apart from troll-line fishing for tuna (see Serventy 1947) no sustained fishing operations of research vessels are available for use in a study of abundance.

Regular observations from vantage points on the land may be expected to throw light on the occurrences of shoals of such species as habitually work very close to the shore, such as Australian "salmon" in particular, horse-mackerel to a much lesser extent, and a few other species to some degree, and one set of data is available which incorporates the results of such observations.

Commencing in September 1936, and continuing in fairly regular sequence until March 1943, the New South Wales State Fisheries Department instituted a system of weekly reports from their inspectors, stationed along the south coast. These were augmented in 1939 by similar reports from the shark meshing inspector, operating by sea along the coast from the Hawkesbury River to Botany Bay Heads. The reports contain records of the occurrences, from week to week, of shoal fish observed by, or reported to, the several inspectors and were received from the following districts of the coast south from Sydney: Botany Bay; Port Hacking; Lake Illawarra (an inlet off the sea); Greenwell Point; Bateman's Bay; Narooma; and Merimbula.

In some districts the possibilities of direct observation or of the receipt of reliable reports of oceanic occurrences were of an extremely low order, since the inspectors and fishermen were primarily concerned with inlet or bay fishing. This applies particularly to Botany Bay and Greenwell Point. In the analyses given later it is important, therefore, to regard the figures adduced as minima.

On some occasions, the inspectors gave estimates of the actual quantities of fish observed; e.g. one report from Merimbula estimated a total Australian "salmon" occurrence in that district as 50,000 boxes (approximately 1,600 tons) for the week. This system was not, however, consistently adopted, nor was any regular attempt made to record the actual number of shoals, hence the reports cannot be analysed on either basis.

* The "salmon" fisheries, which are mainly located in Victoria, New South Wales, and Tasmania, have recently, owing to the establishment of canneries, achieved a fair degree of importance; the total annual catch averaged about 4,000,000 lb. over the years 1936-1944. The mean annual production of sea garfish and kingfish (yellowtail of the southern States) is not known exactly at the time of writing, but for each fish would be of the order of 10-20 per cent. of that of the "salmon." There is a fishery for horse-mackerel in Tasmania, and for pilchard and anchovy in Victoria, which is in each case even smaller in output, and rather sporadic. All these are based entirely or largely on inshore netting operations.

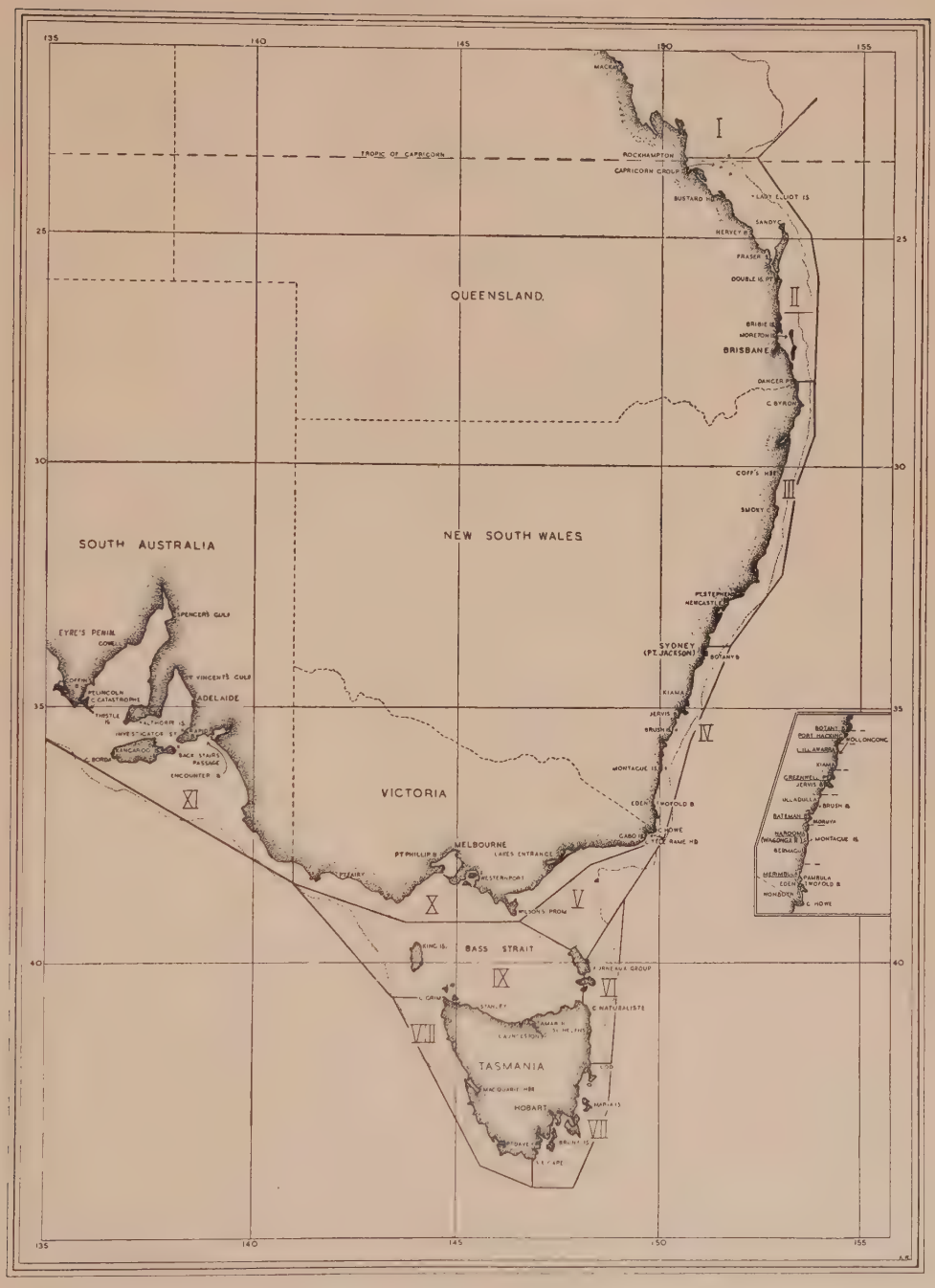

FIG. 1

South-eastern Australia, showing the numbered sectors and localities referred to in the text, and the boundary of the continental shelf. The inset shows the boundaries of the New South Wales south coast inspectors' districts referred to in the text.

The reports refer to several species but, in this analysis, the following only are included on the basis of the definition of "shoal fish" outlined below: Australian "salmon," horse-mackerel, kingfish, and sea garfish (scombroids are omitted). The reports relating to "pilchards" are rather unreliable since it is known that they may refer at times to other (estuarine) species of small fish besides the pilchard. The reports utilized in this study cover the period from September 1936 to December 1941.*

For each district each year, the total number of reports received was ascertained, and the number and percentage of positive reports established for each species.

To compare the shoal occurrences from year to year, the percentage of positive reports of each species for all districts was found; and, to demonstrate seasonal fluctuations in occurrence, the numbers of positive reports for each month in each year were tabulated, totals taken in respect to individual months over the period 1937-1941, and the percentages computed. For most of the species discussed herein, the number of reports per month was too few to permit dissection on the above system for individual districts, and it is therefore not possible to compare the seasonal fluctuations from district to district. Moreover, the conditions obtaining in the several districts, geographical and otherwise (including "personal error"), preclude any attempt to compare the districts even on the basis of years.

In all, the limitations of the available data are so marked that the final percentage computations should be used only as collateral evidence to aid the assessing of the total of evidence assembled in this paper.

These inspectors' reports are based not only on records of shoals seen from the land, but also on those reported by boats, and it is evident that shore observations upon shoals are, for some species, of limited importance.

Aerial observations have since 1936 played an appreciable part in the Council's survey work upon pelagic fish. These observations were mainly intended to indicate broadly the general patterns of geographical and seasonal distribution of the various pelagic fish, which could then be checked and filled in in detail by the boat surveys. This was often the sequence of events.

However, it is obvious that boat surveys provide, on the whole, the most suitable material available for studies of this kind; since conclusions based on the experience of boats could be taken to indicate, at least in a general way, what would be the experience of other boats, including commercial fishing craft, in respect of locating shoals. Furthermore, the records of the boat surveys provided the bulk of the total data available for the south-eastern Australian region generally, and the possibilities of non- or mis-identification of shoals,

* In discussing the results obtained from the analyses of these reports, only the complete years 1937-1941 are considered. Figures for September to December 1936 are not included, since in species showing marked seasonal fluctuation they are heavily weighted; e.g. tuna . . . . 1936 showed 20·5 per cent. positive reports, 1937-41 showed a range of 5·7–8·6 per cent. positive reports; again, kingfish . . . . 1936 showed 9·0 per cent. positive reports, 1937-41 showed a range of 12·0–16·5 per cent. positive reports.

in respect of the constituent species, are minimized where boats are employed. Fine differences of shoaling behaviour can usually be observed more closely from boats and frequently specimens can be captured.

Therefore, the quantity index adopted in this investigation was the percentage ratio of the number of days on which fish shoals of the species in question were observed, to the total number of days or parts of days on which the survey vessel was at sea—in the area and during the period (month or season) in question. It is clear that this index is very far from being ideal, but it is believed that its limitations have been properly emphasized in the following pages. Furthermore, there is evidence that it is for one important species a reliable index of the abundance of the fish stocks.

The sources of data which were available for this, the main part of the study, consisted of the logbook records of the Organization's vessel *Warreen,* which contributed the great bulk of the information, and seven other vessels, three belonging to the Tasmanian Government and four (including three Tasmanian) being privately owned.* The keeping of these logbooks was entrusted to experienced and responsible individuals, who were directed to look out for and record shoals.

For each vessel, every day or part of a day when the boat was actually at sea in the particular area, irrespective of weather or any other consideration, has been included in the tabulated data presented subsequently. Full days spent sheltering in anchorages have been excluded, since the chances of noticing fish shoals under such conditions are very small. In the sense used here, a day is a twenty-four hour period from midnight to midnight, and a fish shoal is a dense concentration of fish very close to or actually breaking the surface of the sea; in such a way that the observer sees a circumscribed and, at any given moment, a fairly well-delimited area whitened with foam, or coloured by the fish themselves, or both.† Very loose concentrations of fish, and fish swarms swimming below the surface, have not been recognized as true " shoals," although a few may have been wrongly recorded as such. These concentrations were excluded to eliminate doubt in the method of recording them. The object has been to make the system of recording shoals as simple and consistent as possible, and in the experience of the writers (who were personally responsible for many of the observations and records made) there were in practice few cases in which much doubt was felt as to how a fish concentration should be recorded. Shoals whose presence was indicated only by the diving of seabirds were excluded from the record, since doubt would arise regarding the real status of the fish swarm being worked, and the identity of the species. It was also considered that fishermen observers might not record such occurrences as faithfully as they would the more concrete evidence of the actual shoals.

However, this restriction in the usage of the term obviously tends, in respect of each species, to depress the quantity index below its real level; a tendency which is important as some of the concentrations excluded from the shoals

* Some records are also available for another private vessel, the *Viking,* and these have also been utilized in the present study; however they refer only to a rather small district (Jervis Bay).

† This definition applies to daytime shoals; some shoals can be recognized at night by their luminescence.

category would be suitable for fishing. Owing to differences in shoaling behaviour, this lowering effect is not constant from species to species. This matter is discussed later for each species. On the other hand no true shoal has been excluded from the records on account of smallness, brevity of occurrence, or of weather or other conditions under which it was seen, although small or momentarily visible shoals may have been overlooked at sea.

It is desirable at this stage to stress again another point which is more fully discussed later: namely, the measures of abundance of shoals as here defined are not *necessarily* related to the abundance of the total fish stock in any particular case.

It remains to mention the manner in which the quantity index has been used. The following résumé will be more clearly understood if reference is made to some of the tables in the text, e.g. Tables 2-4. For each main area, all boat-days of observations, irrespective of vessel employed, are totalled for each calendar month, all years combined. For each month the total number of boat-days on which shoals of each species were seen is then also tabulated, and expressed as a percentage. It is then possible to decide, by inspection of these monthly percentages, the optimum shoaling season for each species. The totals of boat-days of observation at sea (S) and boat-days on which fish shoals were seen (F), and the corresponding percentages ($100\ F/S$), are then tabulated in respect of each year during the optimum season. The next step is to compare abundance of shoals from year to year at the optimum season. This cannot be done directly because the percentages have widely differing bases, but there is a statistical method, the χ^2 test, available for the purpose. An overall percentage for the entire total of seasons is established, and the hypothesis, that this correctly represents the position for each individual season, is tested (see Snedecor 1940, pp. 171-172). If the hypothesis survives the test it is concluded that there is no noticeable tendency towards annual fluctuation in abundance of shoals. If not, it must be inferred that the species in question, in the area under consideration, is subject to yearly fluctuation in abundance.

The records may contain some individual errors of identification of species composing a shoal, but these would certainly be too few to affect the conclusions drawn. After some experience of viewing shoals of different species the observer soon becomes aware of the differences, and, although most shoals seen have not been sampled, specimens from enough of them to permit the identification of different types of shoals have been obtained. Furthermore, the differences recognized by the Organization's officers from experience conform to those recognized by professional fishermen with experience of pelagic fish. It was impossible to record the numbers of the shoals of each species seen on each boat-day. Sometimes the shoals have been too numerous to be counted, and when shoals are breaking up and re-forming counting becomes impossible. It has only been possible to distinguish between cases where one shoal only was logged and where there were more shoals.

Except for pilchards, the data on shoal occurrences relate almost entirely to daylight observations. Pilchard shoals may be recognized on dark (moonless) nights by their luminescence in the water, and have been so recorded on many occasions. Apparently this is not so with other species mentioned here, except the true mackerel.

The waters traversed during the Organization's investigations extend from Mackay in central Queensland, latitude 21° S., southward along the eastern seaboard, between longitudes 145° and 155° E., to south of Tasmania in latitude 44° S.; and westward through Bass Strait along the southern coast of the Australian mainland, generally between latitudes 35° and 40° S., to Coffin's Bay in South Australia, longitude 135° E. (Fig. 1). However, much of this great area was very little visited, by far the major part of the time being spent in the area between Brisbane and Hobart, on the eastern seaboard. This is made clear in Table 1, showing the numbers of boat-days spent in the various sectors by research craft, as at the end of December 1944.

TABLE 1

Sector	Boat-days (No.)
1. Queensland, north of the Tropic	4
2. Queensland, south of the Tropic	55
3. New South Wales, north coast (north of Sydney)	134
4. New South Wales, south coast (south of Sydney)*	330
5. The Paddock†	38
6. North-eastern Tasmania, including east of Furneaux Islands	131
7. South-eastern Tasmania	501
8. Tasmania, west coast	4
9. Bass Strait, including Tasmanian north coast and west of Furneaux Islands	35
10. Victoria	34
11. South Australia‡	31
Total, South-Eastern Australia	1,297

* Excluding 241 days for the Jervis Bay district only, 1943-1945, whose records are discussed subsequently.

† That part of the Tasman Sea immediately eastward of Bass Strait, contained in a triangle of which the points are Wilson's Promontory, Cape Howe, and the Furneaux Islands.

‡ As is mentioned subsequently, there was actually more time than this spent in these waters, but the records of the balance did not lend themselves to the same kind of analysis.

It will be seen that only four areas, as recognized here, have been sufficiently surveyed to permit drawing conclusions as to abundance of pelagic fish shoals; these are the waters of the north and south coasts of New South Wales, and of north-eastern and south-eastern Tasmania. Early in the Organization's boat surveys these four sectors showed more promise of developmental possibilities than the others (except South Australia); consequently they received almost exclusive attention after the beginning of the war. However, further survey work in other areas might present them in a much more favourable light.

In the sectors mentioned the survey was based mainly on the waters of the continental shelf, and the research craft spent relatively little time in the more offshore waters and never ventured far into them. The reasons for this were partly the small vessels available (the *Warreen,* the largest, was 82 feet long), and the fact that these outside waters seemed devoid of pelagic

fish shoals. The aerial surveys, in all sectors, showed that the shoals were confined to the shelf waters, and boat survey work done outside this zone confirmed this view.

Except for a few small areas in which fish are hardly ever found, there is in general little to choose between different places within any one main sector, from the point of view of locating shoals. The research craft which operated in a particular area did so over all or the greater part of that sector,* and, with one partial exception (the *Liawenee,* much of whose time was devoted to Danish-seining, although this work did not remove her from pelagic fish areas), they were always actively looking for fish and following up any clue that might lead to their discovery. In other words the results presented here in respect of any sector may be taken to represent fairly accurately the position that would be found by a commercial craft actively seeking pelagic fish within those waters.

III. Data and Analysis

1. *Queensland, North of the Tropic*

The data are negligible, and are merely included here for completeness. The *Warreen* spent four days in the area in July 1939, the northernmost point reached being Mackay. No shoals were seen.

2. *Queensland, South of the Tropic*

The area extends from the Tropic of Capricorn south to the New South Wales border (Point Danger).

The data are insufficient to warrant any clear conclusions being drawn. The *Warreen* spent 25 days in the area during 1938 and 1939, and the private vessel *Pasadena II.* spent 30 during 1941, making 55 in all. These covered the following periods: September 1938 (11 days); May 1939 (8); July 1939 (6); June 1941 (15) and July 1941 (15). Apart from scombroid or presumed scombroid fishes, the records of shoals all refer to the last of these periods. These were: one of kingfish (*Seriola grandis*) in the Capricorn Islands; one of unidentified "bait fish" off Bustard Head; several large shoals of anchovy (*Engraulis australis*) seen on two days off Sandy Cape, once (with shoals of mullet, *Mugil dobula*) from the shore, and identified from specimens; and shoals of pilchards (*Sardinops neopilchardus*) seen twice on one day, off Double Island Point and Bribie Island.

There is also a reliable record of the occurrence of large and numerous pilchard shoals in the general region between Double Island Point and Lady Elliott Island, in September 1942.

With regard to pilchards, it has previously been shown (Blackburn, 1941, pp. 21, 34-35, 37-39) that these occur as far north as Sandy Cape, at times apparently in at least fair concentrations. The best evidence available on this point is that of the distribution of eggs and larvae in the plankton, from which it appears that the optimum season in these waters is probably the early spring (*l.c.*, pp. 35, 39). The same may be true of the anchovy (*l.c.*, pp. 84-86) but

* Except for the *Viking,* which operated almost wholly in the Jervis Bay area of the New South Wales south coast, as mentioned in previous footnotes.

the evidence is very incomplete; in all probability this species is in any case much less abundant than the pilchard, at least in the open waters (*l.c.*, pp. 81, 84). There are as yet no indications that either species occurs north of the Tropic.

Several species of tuna occur in these waters, to which some reference is made by Serventy (1941*a*; 1942*a*, *b*).

The range of the Australian "salmon" is limited, for all practical purposes, by the 30th parallel of South latitude. On rare occasions outliers of the main stock may extend into southern Queensland waters, but never is the quantity of fish available sufficient to affect significantly the catch statistics of that area. The fish usually referred to in Queensland as the "salmon" belongs to the group of threadfins (*Polynemidae*), and is no more related to the Australian "salmon" (*Arripis trutta*) than this latter species is related to the true salmon (*Salmonidae*) of the northern hemisphere.

3. *New South Wales, North Coast*

(*a*) *General.*—The area extends from the Queensland border to Port Jackson, but observations made off the latter port have been included with the south coast data.

There was a total of 134 days spent in this area, 130 by the *Warreen* (1938-1942) and four by the *Pasadena II.* (June 1941). Most months of the year were "sampled" at least once. The entire area was well traversed on many occasions, although the sector from Coff's Harbour northwards received somewhat less attention than the rest. The data on shoals (excluding scombroids) are summarized in Table 2.

TABLE 2

NEW SOUTH WALES, NORTH COAST. SUMMARY OF OBSERVATIONS, BOTH VESSELS, ALL YEARS COMBINED (EXCLUDING TUNAS)

Month	Total Days	Days Pilchard Seen	%	Days "Salmon" Seen	%	Days Others Seen*	%
January	34	11	32·4				
February							
March							
April	6	4	66·7			1	16·7
May	8	2	25·0				
June	20	4	20·0				
July	15	4	26·7				
August	21	9	42·9				
September	20	4	20·0	1	5·0	1	5·0
October	5						
November							
December	5						
Total	134						

* September occurrence was reported as kingfish, other not identified.

(*b*) *Pilchards.*—It is apparent from Table 2 that the optimum season is from April to September, although there is no evidence for February and March, and shoals seem fairly abundant in January. According to the evidence of distribution of eggs and larvae, and of maturity stages (Blackburn 1941, pp. 35, 39, 42-43), the spawning fish are most numerous on this coast in winter, but also to some extent (depending upon locality) in the late autumn and early spring, and thus the period April to September probably represents the season of occurrence of the spawning (or spent) shoals.* On the other hand the January pilchards are not approaching maturity and have a much higher oil content (loc. cit. pp. 43, 45), indicating that they should be regarded as a separate occurrence. However, the matter warrants clarification by observations in February and March, and more between October and December.

The above records for this optimum period April to September have also been tabulated for separate years. This information, with values of χ^2 and a summary of this test, is given in Table 3.

TABLE 3

NEW SOUTH WALES, NORTH COAST. PILCHARD SHOALS, APRIL-SEPTEMBER

Year.	Total Days	Days Fish Seen*	Days Fish Not Seen*	Days Fish Seen (%)	χ^2
1938	12	2 (3·60)	10 (8·40)	16·67	1·016
1939	46	13 (13·80)	33 (32·20)	28·26	0·066
1940	19	10 (5·70)	9 (13·30)	52·63	4·634
1941	4	(1·20)	4 (2·80)		1·714
1942	9	2 (2·70)	7 (6·30)	22·22	0·322
Total	90	27 (27·00)	63 (63·00)	30·00	7·752

* Numbers in brackets are expected numbers.

In this case $\chi^2 = 7{\cdot}752$, and for $df = 4$, $P > 10$ per cent. (only slightly), < 20 per cent., non-significant. There is no real evidence of annual fluctuation in abundance, although one of the individual values is higher than the 5 per cent. It can be said that pilchards were at about the same level of abundance in five successive years at this season, which level was such that shoals would be found by a vessel on an average of 30 per cent. of days spent at sea. There would thus be a high expectation of a boat finding shoals as frequently as this in any year over this season.

Similar information for January is set out in Table 4.

In this instance $\chi^2 = 1{\cdot}403$, and for $df = 2$, $P > 30$ per cent., nearly 50 per cent., non-significant. The conclusion is similar to that in the last case, i.e. there is no evidence of annual fluctuation.

* These shoals may, however, contain a proportion of fish of the same general size, but not mature.

TABLE 4

NEW SOUTH WALES, NORTH COAST. PILCHARD SHOALS, JANUARY

Year	Total Days	Days Fish Seen	Days Fish Not Seen	Days Fish Seen (%)	χ^2
1940	13	3 (4·21)	10 (8·79)	23·08	0·515
1941	10	3 (3·24)	7 (6·76)	30·00	0·027
1942	11	5 (3·56)	6 (7·44)	45·45	0·861
Total	34	11 (11·01)	23 (22·99)	32·35	1·403

As mentioned previously, pilchard shoals are detectable by night (if moonless) as well as day. A comparison of the day and night occurrences is summarized in Table 5.

TABLE 5

NEW SOUTH WALES, NORTH COAST. PILCHARD SHOALS, DAY AND NIGHT OCCURRENCES

Season	Days Fish Seen	Days Fish Seen (Day Only)	Days Fish Seen (Night Only)	Days Fish Seen (Day and Night)
January	11	3	7	1
April–September	27	17	4	6
Combined	38	20	11	7

These data indicate that during the main season April to September shoals are commoner by day, even allowing for the fact that there were, in these surveys, rather fewer opportunities for observation by night. However, in January the fish are commoner by night.

On most days on which shoals were seen, there were more than one, as shown by the following Table 6.

TABLE 6

NEW SOUTH WALES, NORTH COAST. PILCHARD SHOALS, SINGLE AND PLURAL OCCURRENCES

Season	Days Fish Seen	Days Shoals Single	Days Shoals Plural
January	11		11
April–September	27	4	23
Combined	38	4	34

The question of the identification of pilchard shoals in New South Wales has previously been discussed elsewhere (loc. cit. pp. 26-27). Particularly on the north coast, virtually all shoals of small fish encountered by day in the open waters exhibited the same type of shoaling behaviour ("flipping") that is characteristic of pilchard species in other countries, and a large number were definitely identified as pilchard swarms from specimens netted, killed by gunfire or obtained from tuna and seabird stomachs. Except for occasional true mackerel (*Pneumatophorus australasicus*) mixed with the pilchards, no shoal that was so sampled ever yielded specimens of any other species. The night luminescence is characteristic of pilchard shoals overseas, and some of these night shoals were also identified from netted specimens.

The presence of pilchard concentrations was often inferred from the diving of gannets, even though no fish could be seen. However, these occurrences are not included here, and few of them would have been fishable by surface nets, since pilchards under attack from these birds are fast-moving, and frequently submerge and reappear at brief intervals. On the other hand the diving of the birds at a distance sometimes led to the discovery of real shoals at the surface when the vessel moved over to the place in question. Taking the optimum season as a whole, the shoals seemed liable to occur with equal frequency all along this sector of shelf waters, although the January occurrences were nearly all from the Port Stephens district.

A typical New South Wales pilchard shoal is seen in Plate 1, Fig. E.

No anchovy shoals have been recognized in this area; however, the evidence of planktonic stages indicates that the species can occur in the open shelf waters, though much more rarely than the pilchard (loc. cit. pp. 81, 84-86).

(*c*) *Tunas.*—Several tunas are found in this area, as noted by Serventy (1941*a*, 1942*a*, 1942*b*).

(*d*) *Australian "Salmon".*—From Table 2 it will be seen that only one shoal of Australian "salmon" was recorded (September 1939, by the *Warreen*). The Australian "salmon" is a significant, but not important, item in the commercial fishery of this area. The intrusion of the species into the area northwards from Port Jackson varies considerably from year to year, and, since it does not command a high degree of popularity on the fresh-fish market, the fishery is affected appreciably by the supply of more popular kinds.

The relation of the Australian "salmon" to the other species considered in this paper is discussed fully later, and the single occurrence of a visible shoal listed by the surveying vessel, during 134 days spent in the area, must be considered of no significance in assessing the importance of the species in this area.

4. *New South Wales, South Coast*

(*a*) *General.*—The area extends from Port Jackson to Gabo Island, and records from the offings of both these places are included here.

Representative data for this area as a whole are available from the records of 330 days spent there by the *Warreen* (1938-1942). Every month of the year was "sampled" once, and most months more frequently. Some records are

available from other vessels for the period August to October 1944, but these are not included since they refer to an isolated year (there were no similar observations in 1943), whereas the rest of the data fall into an unbroken sequence of years and thus readily lend themselves to analysis. However, there are also records for a further 241 days (1943-1945) for one part of the coast only, the important Jervis Bay area, which warrant separate consideration; these were personal observations of the late Captain A. Flett, made from his vessel, the *Viking*.

A summary of the *Warreen's* observations month by month, all years combined, is presented in Table 7. Because the tuna (and true mackerel) records have been omitted, the most striking differences between this area and the last one, in respect of pelagic fish occurrences, are not apparent. It must therefore be stated briefly that the two most important tunas of the New South Wales waters, the striped tuna (*Katsuwonus pelamis*) and southern bluefin (*Thunnus maccoyii*) are much more characteristic of the south coast than the north, and indeed the latter form is virtually absent in north coast waters. This is indicated by Serventy (1941*a*, pp. 27, 39), Thompson (1943, p. 284) and Fowler and Serventy (1944, p. 2). There are other important differences between the two areas in this connection, which will be mentioned in the sections dealing with pilchards and "salmon", but these are not obvious from Table 7. The entire area was very thoroughly traversed on numerous occasions, though more time was spent in the waters around and to the south of Jervis Bay than to the north of that district, because the tunas were in most years more abundant in the more southern waters.

TABLE 7

NEW SOUTH WALES, SOUTH COAST. SUMMARY OF OBSERVATIONS, ALL YEARS COMBINED (EXCLUDING TUNAS AND MACKEREL)

Month	Total Days	Days Pilchard Seen	%	Days Anchovy Seen	%	Days "Salmon" Seen	%	Days Others Seen*	%
January	21					3	14·3	1	4·8
February	28	4	14·3	2	7·1	2	7·1		
March	6	1	16·7						
April	13	5	38·5						
May	16	5	31·2			1	6·3		
June	25	10	40·0						
July	5								
August	21					1	4·8		
September	14	1	7·1			2	14·3		
October	57	7	12·3					1	1·8
November	75	14	18·7			1	1·3	4	5·3
December	49	4	8·2			1	2·0	1	2·0
Total	330								

* One November occurrence, and the December one, refer to kingfish; another November occurrence was scad, or yellowtail (*Trachurus declivis*); the October occurrence was possibly cowanyoung, or horse-mackerel (*T. novae-zelandiae*); and the others are doubtful

(*b*) *Pilchards (and Anchovies)*.—Two optimum seasons for pilchards appear from Table 7, one from April to June (or, in a wider definition, February to June), and the other (less important for abundance of shoals) from September to December. According to the evidence of the distribution of eggs and larvae, and of maturity stages (Blackburn 1941, pp. 35, 39, 42-43; see also details in Table 1 of that paper), the occurrence of spawning fish reaches its optimum in autumn, but the spawning season actually ranges from the summer to the early winter; this agrees tolerably well with the above-mentioned period, which can be taken as the season of spawning, spent, and perhaps (in February and March) maturing shoals*. It has been shown (loc. cit., p. 116) that the spring occurrences on this coast consist mainly of smaller, immature fish, and are thus quite distinct from the runs earlier in the year.

Considering first the question of the abundance of the older pilchards during the season February to June, the data are summarized in Table 8.

TABLE 8

NEW SOUTH WALES, SOUTH COAST. PILCHARD SHOALS (ADULTS), FEBRUARY-JUNE

Year	Total Days	Days Fish Seen	Days Fish Not Seen	Days Fish Seen (%)	χ^2
1939	15	(4·26)	15 (10·74)		5·950
1940	40	11 (11·36)	29 (28·64)	27·50	0·016
1941	16	9† (4·55)	7 (11·45)	56·25	6·081
1942	17	5 (4·83)	12 (12·17)	29·41	0·008
Total	88	25 (25·00)	63 (63·00)	28·41	12·055

† On one of these days over a hundred separate shoals were seen, the greatest number of shoals of any species ever seen in any area during these boat surveys.

Here $\chi^2 = 12.055$, and for $df = 3$, $P < 1$ per cent., highly significant. One concludes that these pilchard occurrences are subject to annual fluctuations; the overall abundance index (shoals on 28 per cent. of days at sea) has little real meaning.

Taking the position of the same run of fish during the more restricted period, April to June, the position is shown in Table 9.

In this case $\chi^2 = 11.904$, and for $df = 3$, $P < 1$ per cent., highly significant. The percentages are greater, but they and the values of χ^2 parallel almost exactly the previous set. The conclusion is the same, that there are annual fluctuations in these pilchard runs.

* However there is some evidence that these shoals contain a proportion of fish which, though of the same general size, are immature.

Table 10 contains similar information about shoals of young pilchards for the season September to December.

Here $\chi^2 = 13.262$, and for $df = 3$, $P < 1$ per cent. highly significant. These runs, too, appear to be subject to annual fluctuations in abundance; the overall index has little real meaning. These fish are much less abundant in shoals during their season of occurrence than the older pilchards.

TABLE 9

NEW SOUTH WALES, SOUTH COAST. PILCHARD SHOALS (ADULTS), APRIL-JUNE

Year	Total Days	Days Fish Seen	Days Fish Not Seen	Days Fish Seen (%)	χ^2
1939	10	(3·70)	10 (6·30)	..	5·873
1940	22	8 (8·15)	14 (13·85)	36·36	0·005
1941	11	8* (4·07)	3 (6·93)	72·73	6·024
1942	11	4 (4·07)	7 (6·93)	36·36	0·002
Total	54	20 (19·99)	34 (34·01)	37·04	11·904

* See footnote to previous table.

TABLE 10

NEW SOUTH WALES, SOUTH COAST. PILCHARD SHOALS (JUVENILES), SEPTEMBER-DECEMBER

Year	Total Days	Days Fish Seen	Days Fish Not Seen	Days Fish Seen (%)	χ^2
1938	38	1 (5·07)	37 (32·93)	2·63	3·770
1939	35	3 (4·67)	32 (30·33)	8·57	0·689
1940	68	17 (9·06)	51 (58·94)	25·00	8·028
1941	54	5 (7·20)	49 (46·80)	9·26	0·775
Total	195	26 (26·00)	169 (169·00)	13·33	13·262

If the percentage occurrence of these young fish over the four seasons 1938 to 1941, and those of the older ones over the four seasons 1939 to 1942, are depicted as in Figure 2, there is an obvious positive correlation between the abundance in any season September to December and that in the subsequent season April to June (or February to June). The correlation coefficient is statistically significant where the April to June season is considered ($r = 0.956$, $df = 2$) and almost so where the February to June season is taken ($r = 0.949$, whereas at the 5 per cent. level of significance for $df = 2$, $r = 0.950$). This is what

would be expected on biological grounds, since there is now evidence* to show that the small spring pilchards, with modal total length about 3¾ to 4½ in., are mostly about 1¼ years old, while the autumn and early winter fish are predominantly individuals with modal total length about 5½ to 6 in., and about two years old (although there are some fish at greater ages, up to at least six years). The spring fish are apparently leaving the bays and estuaries they entered as postlarvals a few months after hatching at sea (and in which they pass a full year of life) to join the open sea stock which spawns (in part) and shoals in the autumn and winter. Hence it would be expected that the above type of correlation would apply, and the fact that it does is regarded as testifying to the reliability of the boat observations in affording an index of abundance of the stock of pilchards.

It is obvious that, since the spring and autumn-winter fish are about 1¼ and (mostly) 2 years old respectively, the poor spring run of 1938 and poor autumn-winter run of 1939 must have derived from a poor spawning, or survival of spawn, in the autumn-winter of 1937; and similarly that there was abundant spawning, or good survival, in 1939, and intermediate conditions in 1938 and 1940. This is based on the well-known theory, deriving initially from Hjort (1914), that many natural fluctuations (of which this is an example) depend in part upon actual egg production, but especially upon differential survival rates, arising from differing environmental conditions for broods of larvae and postlarvae in different spawning seasons. The special importance of this survival factor seems to be well illustrated in the present case: since no pilchard shoals were seen in the 1939 spawning season, the fish must have been scarce and the amount of spawn produced much less than in a "normal" year; but since the 1939 pilchard brood was numerically strong, environmental conditions during the winter must have been favourable for the survival of larvae and postlarvae. As the marine environment is the subject of investigations (hydrological and planktological) by this Organization it seems that, if the establishment of a fishery warranted it, some form of fluctuation prediction service could be operated. This could take the form of a study of the relative abundance of young stages available in each spawning season, as determined from plankton catches.

Two interesting conclusions follow from the foregoing observations on the south coast pilchard runs. There is no reason to suppose that the life-history of the pilchard during its first year or so of life is different on the north coast from that on the south coast, where it resembles that for the pilchard of Europe (see De Buen 1937, pp. 407-410). Hence it seems almost certain that there is a spring run of small fish on the north coast, in addition to the main winter occurrence (which again consists mainly of 2-year old fish). Reference to Table 2 shows that little survey work has been carried out in those waters during the months October to December—insufficient to reveal such shoals at the general level of abundance found on the south coast; a further search may reveal the presence of such a spring run, probably associated (as on the south coast, see Blackburn 1941, p.116) more closely with the bays and estuaries.

* Blackburn, M. (1949). "The age, rate of growth and general life-history of the Australian pilchard (*Sardinops neopilchardus*) in New South Wales waters." Common. Sci. Industr. Res. Org., Aust., Bull. No. 242.

The other conclusion is that the pilchards of the north and south coasts may belong to two different populations, not mingling significantly, or perhaps to two different groups of quasi-independent populations. The line of demarcation may not be at Port Jackson, but somewhere in that general region. If there were any substantial intermingling of the grown pilchards themselves, it would take place after the emergence of the fish from the bays and estuaries at about 1¼ years of age, and there would be no contrast between the annual fluctuations on the south coast and the stable level of abundance on the north. Extensive intermingling of larvae or postlarvae between the two areas seems a remote possibility.

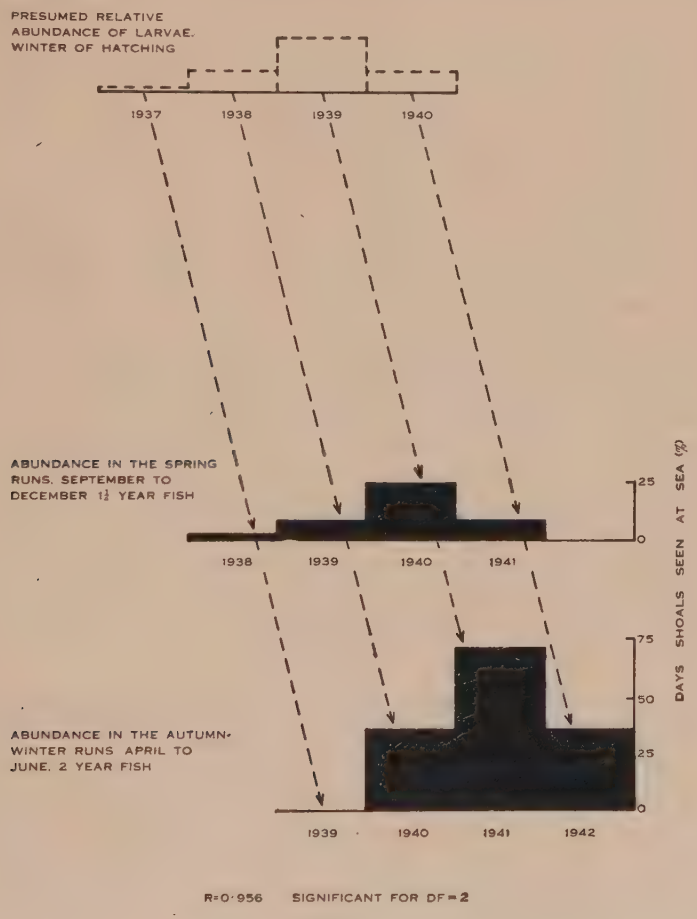

FIG. 2

Correlation between abundance of pilchard shoals in the spring and the autumn–winter following, on the New South Wales south coast. For further explanation see text.

It is of interest here to consider the records compiled by Captain Flett for the Jervis Bay region. This area would undoubtedly prove an important centre for any future pilchard fishery in these waters. Flett's observations, made from

October 1943 to September 1945, refer to a sector of coastal waters extending from the vicinity of Kiama to Brush Island, i.e., about 30 to 40 miles north and south of Jervis Bay. The data on shoals are presented in Table 11.

TABLE 11

JERVIS BAY REGION. SUMMARY OF OBSERVATIONS, ALL YEARS COMBINED (EXCLUDING TUNAS AND MACKEREL)

Month	Total Days	Days Pilchard Seen	%	Days "Salmon" Seen	%	Days Others Seen*	%
January	17	5	29·4				
February	15	7	46·7				
March	19	2	10·5				
April	18	3	16·7				
May	23	6	26·1	1	4·3		
June	31	6	19·3				
July	39	9	23·1				
August	18	1	5·5				
September	13					2	15·4
October	11	1	9·1			1	9·1
November	19	2	10·5				
December	18	3	16·7			1	5·5
Total	241						

* The September occurrences were of barracouta (*Thyrsites atun*) and king-fish; the October one was of trevally (*Caranx georgianus*), and the December one of cowanyoung, or horse-mackerel.

It is not so easy to pick out the separate seasons in this case, but if the percentages from October to August are to be divided into two groups the most reasonable dividing line is the month of March. This would indicate about October to February and April to August as the two optimum seasons, which could be identified with the two main seasons already recognized for the south coast as a whole, if there was any reasonable explanation for the one to two months' lag in the starting and finishing dates of each.

This is not hard to find for the autumn-winter season, since it has been shown (loc. cit. pp. 34-35, 38-39) that the optimum season of spawning, and appearance of pilchard shoals, is progressively later in the more northerly waters, along the entire New South Wales coast. (This does not necessarily imply migration of the fish, and thus does not conflict with the conclusion just mentioned, as to the probable existence of separate populations). Thus since Jervis Bay is on the northern part of the south coast one would expect the optimum season for shoaling fish to be somewhat later than that for the south coast as a whole; in fact the succession of dates for all the areas considered here, in respect of the autumn-winter pilchard season, bears out the general argument reasonably well:

All south coast—February to June,
Jervis Bay area—April to August,
All north coast—April to September.

As for the second season, in spring and summer, one could perhaps account for the lag in the dates at Jervis Bay, as compared with those for the whole south coast (there is no information for the north coast) on the assumption that the later in the year the fish are spawned, the later (in the following year) they emerge from the estuaries and bays. This may well be true but there is no evidence for it. Some of the January and February fish could also be the larger fat pilchards, similar to those found on the north coast in January.

Tabulating these Jervis Bay records for the April to August season for the separate years, and calculating χ^2 as before, the position is as shown in Table 12.

TABLE 12

JERVIS BAY REGION. PILCHARD SHOALS, APRIL-AUGUST

Year	Total Days	Days Fish Seen	Days Fish not Seen	Per cent. Days Fish Seen	χ^2
1944	58	12 (11·24)	46 (46·76)	20·69	0·063
1945	71	13 (13·76)	58 (57·24)	18·31	0·052
Total	129	25 (25·00)	104 (104·00)	19·38	0·115

In this case $\chi^2 = 0.115$, and for $df = 1$, $P >$ 90 per cent., $<$95 per cent. non-significant. The level of abundance of shoals was almost the same in these two successive years. However, the period in question is too short to permit the conclusion that this level could be expected to apply in this region in all or most years, and in fact, judging by what has already been shown for the south coast as a whole, any such conclusion would be wrong. The main interest in the results derives from a comparison with the result of a similar test in respect of the data for the season October to February, tabulated by the separate years in Table 13.

TABLE 13

JERVIS BAY REGION. PILCHARD SHOALS, OCTOBER-FEBRUARY

Year	Total Days	Days Fish Seen	Days Fish not Seen	Per cent. Days Fish Seen	χ^2
1943/4	36	8 (8·10)	28 (27·90)	22·22	0·001
1944/5	44	10 (9·90)	34 (34·10)	22·73	0·001
Total	80	18 (18·00)	62 (62·00)	22·50	0·002

In this case $\chi^2 = 0.002$, and for $df = 1$, $P >$ 95 per cent., $<$ 98 per cent., non-significant. The conclusion is the same as before. No correlation coefficient can be calculated in respect of abundance in the spring-summer season as compared with that of the following autumn-winter; but it is clear that these

Jervis Bay data on shoal occurrences agree with the relationship established for the south coast data as a whole, i.e. that relative abundance indices for the spring-summer seasons are paralleled for the following autumn-winter seasons.

In this set of data the spring-summer abundance index is in each case much higher, relative to that for the autumn-winter, than was found for the whole south coast, because for comparable periods of observation, the spring-summer shoals are more often seen at Jervis Bay than elsewhere. For instance, by comparing these percentages in Table 13 with those in Table 10, it might be inferred that the broods which gave rise to the spring-summer runs of 1943/4 and 1944/5, i.e. those of 1942 and 1943 respectively, were as exceptional in numerical strength as was that which gave rise to the spring run of 1940, i.e. that of 1939. However, for purposes of such comparison the autumn-winter indices are to be preferred, and if those in Table 12 are compared with those in Tables 8 and 9 it will be seen that the 1942 and 1943 broods were probably more comparable with those of 1938 and 1940, that is to say of only moderate strength. Thus it is possible to indicate with reasonable confidence the relative strengths of six out of the seven annual broods of south coast pilchards for the years of spawning 1937-1943, the year for which there is no such measure being 1941: 1937 yielding a very poor brood, 1939 a very good one, and 1938, 1940, 1942 and 1943 broods of medium size. The lack of information on the 1941 brood is due to wartime interference with the sea work.

Day and night occurrences on the south coast as a whole are summarized in Table 14.

TABLE 14

NEW SOUTH WALES, SOUTH COAST. PILCHARD SHOALS, DAY AND NIGHT OCCURRENCES

Season	Days Fish Seen	Days Fish Seen Day Only	Days Fish Seen Night Only	Days Fish Seen Day and Night
February–June	25	23	2	
September–December	26	14	9	3
Combined	51	37	11	3

The indication is that during the main season February to June shoals are commoner by day, even allowing for the fact that there were fewer opportunities for observation by night. However, during the September to December season the shoals are probably at least as common by night as by day. There is thus a measure of agreement with the result found for the north coast waters (see above). In both areas the shoals occur mostly by day in the colder months (spawning season) and at least as often by night as by day in the warmer months (pre- or inter-spawning period).

On most of the days on which shoals were seen, there was more than one shoal, as shown by Table 15.

TABLE 15

NEW SOUTH WALES, SOUTH COAST. PILCHARD SHOALS, SINGLE AND PLURAL OCCURRENCES

Season	Days Fish Seen	Days Shoals Seen Single	Days Shoals Seen Plural
February–June	25	6	19
September–December	26	2	24
Combined	51	8	43

For identification of shoals, most of what has been said about the north coast again applies. However, experience has shown that the possibility of a shoal of small fish being of some species other than the pilchard is greater. From Table 7 it is seen that there were two occasions, both in the summer of 1939-40, upon which shoals were seen and definitely identified as anchovies (see below). There were also five occasions, all in the spring of 1940, on which other shoals were seen. These were identified, from netted samples on one or two occasions, and in other cases by comparision with the sampled shoals, as true mackerel (not shown in Table 7). One shoal was also definitely identified as scad (yellowtail), another was thought to be cowanyoung (horse-mackerel), and another, noted as small fish other than pilchard, was not identified. Nevertheless there were not more than perhaps three or four shoals being misidentified as pilchards, since the cowanyoung has, and was known to have, a markedly different shoaling habit; the scad is more an inhabitant of the bays and estuaries than the open shelf waters where most of the observations were made; and the same is true of the anchovy (l.c., pp. 81, 84, 86). The mackerel appears to shoal with the pilchard on this coast (since specimens occur in pilchard catches). It is quite possible that some of the few shoals identified as mackerel, and from which only a few specimens were taken, contained pilchards too. Most of the pilchard shoals were readily identifiable from their characteristic flipping or pattering behaviour, night luminescence, or the direct evidence of samples, and it is clear from the logs that in most cases the observers had no doubt. In a minority of instances there appears to have been some doubt, and in some cases the records refer merely to " small fish," but for reasons already given all such shoals have been listed as pilchards, save in one instance where the log indicates that the fish were not thought to be this species.

South coast pilchard concentrations, though not seen (and hence not included here), were at times inferred from the working of seabirds. Other remarks previously made in that connection also apply. Taking the optimum autumn-winter season as a whole, the shoals generally seemed to occur with much the same frequency all along this sector; but as mentioned, the Jervis Bay region is an especially important area for the spring shoals.

As stated, definite anchovy shoals were found on two occasions, both in the same locality and month (Twofold Bay, February 1940). This species is not plentiful in the open shelf waters, and certainly does not shoal at the surface as frequently as the pilchard. Summer seems to be the optimum season of its occurrence. (loc. cit. pp. 84, 86).

(*c*) *Tunas.*—References to tuna occurrences in this area have been made by Serventy (1941*a*; 1942*a*, *b*, and 1947), Thompson (1943, pp. 284-5) and Fowler and Serventy (1944, pp. 2-3). There are several species but two are especially abundant, the striped tuna and the southern bluefin. The principal season for the latter is given as the spring and early summer; that for the former is not specifically stated for this particular area, but in the experience of the present writers it extends from the late spring throughout the summer, for this coast as a whole. Both Thompson and Serventy (1947, p. 147) refer to important annual changes in abundance of the southern bluefin in these waters.

(*d*) *Australian "Salmon"* (in part).—Following the establishment of canneries at Eden and Narooma, the south coast of New South Wales, between Bateman's Bay and Cape Howe, became the most important "salmon" producing area in Australia, owing to the rapid expansion in the exploitation of the readily available shoals of these fish. Prior to the establishment of these canneries the species was not much in demand by the fresh fish market.

The Australian "salmon" fishery was one of the first objects of fisheries investigation undertaken by the Organization, but it soon became evident that the *Warreen,* concentrating her efforts on the tuna and pilchard survey, could procure little information about the species. This fact is strikingly illustrated in the following Table 16 (see also Table 7), where it is shown that shoals of Australian "salmon," one of the most important and keenly sought fish in the area, were seen on only 3·3 per cent. of boat-days spent in the area, i.e. 11 days in 330.

TABLE 16

NEW SOUTH WALES, SOUTH COAST. RECORDS OF AUSTRALIAN "SALMON" SHOALS (*Warreen*)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1938	*	*	*	*	*	*	*	1					1
1939			*										0
1940	3	2	*		1				2			1	9
1941			*		*		*	*	*		1		1
1942	*	*		*			*	*	*	*	*	*	0
Total	3	2			1			1	2		1	1	11

* Months in which no work was done on the coast.

The lack of " salmon " shoal records in the logs of the *Warreen* is almost wholly due to the extremely restricted zone of that species along the coast. The vast majority of the large shoals of " salmon " travel close to the shoreline, usually within the surf zone, and rarely move to seaward past the 10-fathom line. Only rarely are shoals seen surfacing any further out to sea. Since tunas and pilchards are normally sought in waters of greater depth than 20 fathoms, the results recorded above are not surprising, and the conclusion must be drawn that for Australian " salmon " the evidence as to occurrence adduced from the *Warreen's* records is not significant. Much better evidence is available, and is considered in the following section.

(*e*) *Other species*: *Inspector's reports.*—(i) *General.*—As explained above (pp. 10, 12) the data presented here have limitations, but if they are examined with these in mind certain significant features are evident in particular species.

Tables 17*a*, and *b*, show the number of reports received; Table 17*a* gives the number of reports received per annum per district, and Table 17*b* shows the number of reports received from all districts per month per year. The annual totals for the years 1937-1941 are reasonably consistent in magnitude (244-395), and an examination of the percentage of positive reports for each species derived from these totals may give some indication of trend of occurrence of the species. Similarly, the totals by months for the whole area are reasonably uniform (127-153), except for December (115).

TABLE 17*a*

INSPECTORS' WEEKLY REPORTS

Reports received by Districts

District	1936	1937	1938	1939	1940	1941
Sydney Heads				37	36	45
Botany Bay	17	49	48	51	44	33
Port Hacking	17	48	51	53	52	8
Lake Illawarra	18	46	51	53	49	48
Greenwell Point	18	49	45	48	47	10
Bateman's Bay	18	51	51	53	45	43
Narooma	18	50	49	51	46	16
Merimbula	16	46	49	49	49	41
Totals	122	339	344	395	368	244

TABLE 17*b*

INSPECTORS' WEEKLY REPORTS

Reports received per Month, All Districts

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936									27	33	27	35
1937	25	26	28	33	24	25	33	27	22	35	28	33
1938	28	25	28	33	31	28	26	35	28	27	35	20
1939	35	30	29	38	29	31	38	31	31	39	28	36
1940	30	27	35	27	25	40	31	32	39	32	32	18
1941	30	19	21	21	21	21	21	17	26	20	19	8
Totals 1937–41	148	127	141	152	130	145	149	142	146	153	142	115

In assessing the significance of positive reports on a basis of months 1941 has been included, since although the number of reports received is relatively low, their numbers are fairly consistent. Monthly figures for 1936 have been omitted from the table totals, since they apply only to the spring and summer months and tend to weight the final figures to some extent. These figures are estimated to determine whether the reports would demonstrate seasonal fluctuations in shoal occurrences.

The final positive percentage figures (southern New South Wales) for each species except " salmon " are markedly depressed by negative reports from the Narooma district; and it should be emphasized that, in the Montague Island district immediately east of Narooma, there is a zone from which consistently good reports have, from time to time throughout the period covered by these investigations, been received. These relate to large shoals of kingfish, sea garfish, horse-mackerel, and other pelagic species.

The boundaries of the inspectors' districts are indicated in Figure 1.

(ii) *Australian " Salmon ".*—Full evidence (not presented in this paper) indicates that the great bulk of Australian " salmon " shoals travel in inshore waters, at least within the 15-fathom line, and thus the species lends itself to observation from the shore. Moreover, the operations of canneries at Narooma and Eden have increased the value of the species, which has become one of our most important inshore fish. The occurrence data are summarized in Tables 18*a*, *b*, and *c*.

Positive reports for the whole coast indicate a slight decline from 49·3 per cent. in 1937 to 41·9 per cent. in 1940, which may not be significant, and does not demonstrate a fluctuation trend. It will be seen that the Narooma figures decreased over the same period from 100·0 per cent. to 50·0 per cent., owing to a remarkable change in the habit of the Australian " salmon." The fishery for Australian " salmon " has, in the majority of cases, consisted of a series of steps from area to area. At the beginning of the fishery the shoals exploited were those found in estuary or inlet waters in Victoria, and adjacent to Sydney, New South Wales. The history of each inlet has been the same. Prior to the initiation of a fishery for " salmon," the reports indicated the consistent appearance of large shoals of this species within the inlet. An intensive fishery developed and was profitable for two or three years. Thereafter the " salmon " shoals failed to enter the inlet, although numerous shoals might be seen in the surf near the entrance. It has not been possible to determine the causes of this change of habit, but it is well established that fish do not again enter an inlet after an intensive fishery has been carried out. For instance, at Pambula estuary a fishery for " salmon " developed in 1920 and the fishermen were successful until 1922; since that date no large shoals of " salmon " have been recorded within the inlet, although a well established fishing community operates there and in the adjacent coastal waters. Similarly, for many years before and during the first two years of the operation of the cannery at Narooma, the reports showed the presence of shoals of " salmon " within Wagonga Inlet throughout the year. Towards the latter part of 1938 the change in habit was evident, and since that time " salmon " have failed to enter the inlet, except rarely in very small numbers. Thus, the reports received for 1939, 1940, and

TABLE 18*a*

AUSTRALIAN "SALMON"

Percentages of Positive Weekly Reports

District	1936	1937	1938	1939	1940	1941
Sydney Heads				29·7	33·3	35·6
Botany Bay		2·1		13·8	6·8	15·1
Port Hacking	64·8	20·9	27·5	39·6	32·6	12·5
Lake Illawarra	94·4	71·9	78·4	83·0	77·8	89·7
Greenwell Point	5·6	14·3	4·3	20·8	8·5	0
Bateman's Bay	38·9	37·3	41·2	43·4	28·9	53·6
Narooma	100·0	100·0	89·5	49·0	50·0	31·3
Merimbula	48·8	65·3	83·3	85·9	89·9	95·2
Southern N.S.W.	53·3	49·3	46·7	46·3	41·9	54·1

TABLE 18*b*

AUSTRALIAN "SALMON"

Analysis of Annual Reports

	1936	1937	1938	1939	1940	1941
Negative reports	57	189	183	212	214	112
Positive reports	65	150	161	183	154	132
Total	122	339	344	395	368	244

TABLE 18*c*

AUSTRALIAN "SALMON"

Analysis of Positive Monthly Reports, All Districts

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936									11	17	18	19
1937	11	12	12	18	12	8	12	11	11	13	14	16
1938	15	10	11	17	11	12	15	13	13	13	17	14
1939	16	13	10	10	8	14	19	15	19	26	16	17
1940	10	14	9	5	11	14	15	18	20	18	16	4
1941	11	9	10	7	13	8	12	17	17	9	14	5
Total 1937–41	63	58	52	57	55	56	73	74	80	79	77	56
Percentage Positive	42·6	46·3	36·2	37·5	42·3	38·6	49·7	52·1	54·1	51·6	54·2	48·7

1941 relate only to shoals observed and reported in coastal waters, in contradistinction to the reports of 1936, 1937, and 1938, which refer to shoals noted within the inlet. Outside, shoals are not noticed as frequently as those in the inlet, and thus the percentage of positive reports is smaller in the later years.

The annual percentages by districts show no clear evidence of mass trends, north or south, and the years of minimum occurrence for individual districts occur irregularly throughout the Table, indicating a fairly static condition of the main mass of the fish.

The month-to-month analysis indicates a fairly high level of abundance throughout the year, reaching a maximum during the spring months, August to November, and a minimum in March and April.

(iii) *Sea Garfish.*—Although not the object of extensive fishing, owing to its pelagic habits, the sea garfish (*Hyporhamphus intermedius*) is a significant feature of the coastal waters. The data are presented in Tables 19*a, b,* and *c.*

In this case, as with the Australian " salmon," the apparent decline in the yearly positive percentages may not be significant. The sea-garfish shoals generally occur further offshore than do the " salmon " shoals, and thus are not visible to observers from beaches or headlands.

The monthly analysis indicates a season of maximum occurrence during February and March, with minimum occurrence during the spring.

The annual percentages district by district do not show any evidence of mass movement of the species, and the years of minimal occurrence tend to vary irregularly from district to district. To obtain a more accurate picture of the rate of occurrence, the figures for Narooma should be disregarded, on the basis of the argument expressed on p. 32. This species occurs in all parts of the south-eastern Australian area, and also to the north and west.

(iv) *Horse-mackerel* (*Cowanyoung*).—The shoal habits and movements of this fish along the New South Wales coast are virtually unknown, although it is reported, from time to time, to occur in large quantities in the more southern waters. The final figures given in Table 20*a* are very low, and it is evident that the species is rarely seen, by shore-based observers. However, the figures for Narooma do not constitute very conclusive evidence, and in the Botany Bay and Lake Illawarra districts there is relatively little interest taken in the outside fisheries.

Table 20*c* indicates a marked seasonal fluctuation, the season of maximum occurrence being the late summer and autumn months, from February to May. However, a competent observer reported shoals of this species as being plentiful in the waters near Eden (Merimbula district) from August 1946 to January 1947 (and in the late winter and spring of 1947 and 1948, when some catches were made).

This species is not known to occur on the New South Wales north coast, but ranges south and west through the rest of the south-eastern area, and beyond to Western Australia.

TABLE 19*a*

SEA GARFISH

Percentages of Positive Weekly Reports

District	1936	1937	1938	1939	1940	1941
Sydney Heads						
Botany Bay	23·5	34·7	29·2	23·6	6·5	21·2
Port Hacking	29·4	37·5	45·1	62·3	59·6	62·5
Lake Illawarra	83·5	50·0	68·6	58·5	69·4	58·2
Greenwell Point		8·2	40·0	16·7		
Bateman's Bay		11·8	3·9	22·7	16·7	9·3
Narooma		26·0				
Merimbula	6·3	45·7	34·7	26·6	16·3	31·7
Southern N.S.W.	20·5	30·1	31·7	27·6	22·6	23·4

TABLE 19*b*

SEA GARFISH

Annual Analysis of Reports

	1936	1937	1938	1939	1940	1941
Negative reports	97	237	235	286	285	187
Positive reports	25	102	109	109	83	57
Total	122	339	344	395	368	244

TABLE 19*c*

SEA GARFISH

Analysis of Positive Monthly Reports, All Districts

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936									6	9	3	7
1937	10	16	23	14	10	4	9	4	3	4	1	4
1938	11	9	8	17	13	11	9	6	5	4	10	6
1939	13	12	11	9	11	8	7	5	6	10	5	12
1940	10	8	9	8	7	8	8	9	8	6	2	0
1941	7	5	7	4	5	5	3	3	5	7	5	1
Totals 1937–41	51	50	58	52	46	36	36	27	27	31	23	23
Percentage positive	34·5	39·4	41·1	34·2	35·0	24·8	24·2	19·0	18·5	20·3	16·2	20·0

TABLE 20*a*

HORSE-MACKEREL (COWANYOUNG)

Percentages of Positive Weekly Reports

District	1936	1937	1938	1939	1940	1941
Sydney Heads				43·2	0	13·3
Botany Bay	0	2·0	0	0	0	0
Port Hacking	5·9	0	2·0	24·5	19·2	0
Lake Illawarra	0	0	0	0	0	0
Greenwell Point	0	0	2·2	1·1	0	0
Bateman's Bay	11·1	21·6	27·5	9·4	4·4	0
Narooma	0	0	0	0	0	0
Merimbula	0	0	4·1	18·4	12·2	7·3
Southern N.S.W.	2·5	3·5	5·2	11·1	4·8	3·7

TABLE 20*b*

HORSE-MACKEREL (COWANYOUNG)

Annual Analysis of Reports

	1936	1937	1938	1939	1940	1941
Negative reports	119	327	326	351	350	235
Positive reports	3	12	18	44	18	9
Total	122	339	344	395	368	244

TABLE 20*c*

HORSE-MACKEREL (COWANYOUNG)

Monthly Analysis of Positive Reports, All Districts

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936									0	0	2	1
1937	0	0	2	4	3	0	0	0	0	0	1	2
1938	3	3	4	5	1	1	0	0	0	0	1	0
1939	2	7	5	7	6	3	1	2	0	3	4	4
1940	5	2	4	3	2	2	0	0	0	0	0	0
1941	1	1	2	0	2	1	0	0	2	0	0	0
Totals 1937–41	11	13	17	19	14	7	1	2	2	3	6	6
Percentage positive	7·2	10·2	12·1	12·5	10·7	4·8	0·7	1·4	1·4	2·0	4·2	5·2

(v) *Kingfish.*—In habit the kingfish is somewhat similar to the Australian "salmon," and its normal range of occurrence appears to be within the 50-fathom line, the shoals tending to concentrate in the vicinity of islands and rocky headlands, frequently entering bays and inlets. Nevertheless the species does not frequent the surf zone as does the Australian "salmon," and thus is not as readily observable from the shore.

The occurrence data are presented in Tables 21*a*, *b*, and *c*. The trend evident in the total positive percentages for 1937-1941 may be significant, in indicating a cyclic fluctuation, in view of subsequent reports which indicated an extremely large occurrence of kingfish off the north and central coasts of New South Wales during the summer of 1943-44. The optimum season for shoaling kingfish appears to be the summer.

This species is known to occur throughout the entire south-eastern area, and through to Western Australia, but is probably scarce in Tasmanian waters. It is known as "yellowtail" in the three southern states.

TABLE 21*a*

KINGFISH

Percentage of Positive Weekly Reports

District	1936	1937	1938	1939	1940	1941
Sydney Heads				0	0	8·9
Botany Bay	0	0	0	0	2·3	0
Port Hacking	5·9	14·6	17·6	34·0	57·7	50·0
Lake Illawarra	16·7	19·7	7·8	22·7	16·3	22·9
Greenwell Point	16·7	8·2	2·2	10·4	0	0
Bateman's Bay	5·6	25·7	23·5	2·0	8·9	13·9
Narooma	0	4·0	0	0	0	0
Merimbula	18·8	45·7	46·9	18·4	12·2	21·9
Southern N.S.W.	9·0	16·5	14·2	12·0	13·3	13·9

TABLE 21*b*

KINGFISH

Annual Analysis of Reports

	1936	1937	1938	1939	1940	1941
Negative reports	111	283	295	351	320	210
Positive reports	11	56	49	44	48	34
Total	122	339	344	395	368	244

TABLE 21*c*

KINGFISH

Monthly Analysis of Positive Reports, All Districts

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936									0	1	1	9
1937	8	12	7	3	2	1	0	3	3	2	7	8
1938	5	5	7	5	7	6	1	2	2	1	6	2
1939	5	9	4	1	3	2	3	2	5	6	2	2
1940	7	8	6	4	2	5	2	3	5	1	3	2
1941	11	9	4	0	0	0	0	0	1	1	6	2
Totals 1937–41	36	43	28	13	14	14	6	10	16	11	24	16
Percentage positive	24·3	33·9	19·9	8·6	10·8	9·7	4·0	7·0	11·0	7·2	16·9	13·9

5. *The Paddock*

This is the name given by seamen to that part of the Tasman Sea to the east of Bass Strait, bounded on the west by an imaginary line connecting Wilson's Promontory and the Furneaux Group, and on to the east by one from Gabo Island to Furneaux Islands. Records from the Victorian east coast are not included here.

The data are inadequate, and no conclusions for pelagic fish occurrence can be drawn. There were 38 days spent by the *Warreen* (1938-42) while on passage between New South Wales and Tasmania. There were also two odd days recorded from another source in August and October 1944, on which no fish were seen. Over a part of this route a vessel is beyond the continental shelf. No shoals were seen in the daytime, but there were two night records. In November 1939, a large shoal of unidentified fish was detected by its luminescence, and in August 1940, a large shoal, possibly of "salmon," was heard splashing.

6. *North-eastern Tasmania*

(*a*) *General.*—The area includes the eastern shores of the Furneaux Islands and adjacent waters, and the east coast of Tasmania south from Cape Naturaliste to Cape Lodi.

There were 131 days spent in this area, all by the *Warreen* (1938-42). Every month of the year was "sampled" once and many of them oftener. Records are also available from another source for two single days in August and October 1944, but these are not included since there is a considerable gap between them and the rest of the work, and no shoal fish were reported.

A summary of the *Warreen's* observations month by month, over the combined years, is presented in Table 22. Because the tuna records are omitted, the picture is not impressive, and moreover the most distinctive features of the area do not stand out. Actually this area ranks with the south coast of New South Wales as far as general importance of tuna is concerned, but differs from

it in that striped tuna is more numerous than the southern bluefin, whereas in the south coast waters these forms are more comparable in importance (see Serventy 1947, pp. 140-41). Another importance difference between this area and the New South Wales area is the virtual absence of pilchard shoals. On the other hand, Australian " salmon " is again an important species.

The entire area was thoroughly traversed on many occasions, no part receiving more attention than another.

TABLE 22

NORTH-EASTERN TASMANIA

Summary of Observations, over Combined Years (excluding Tunas)

Month	Total Days	Days " Salmon " Seen	(%)	Days Others Seen*	(%)
January	9				
February	4				
March	18				
April	29	5	17·2	1	3·4
May	18			1	5·6
June	17	1	5·9		
July	7				
August	5			1	20·0
September	3				
October	9				
November	6				
December	6				
Total	131				

* The April occurrence was unidentified, possibly horse-mackerel; the other two occurrences were anchovy.

(*b*) *Tunas.*—According to Serventy (1941*a*) and Fowler and Serventy (1944, pp. 2-3), there are three tunas known from this area, the albacore (*Thunnus germo*) and the two mentioned above. (The albacore occurs in other regions also, but so far has not been found especially plentiful in any of them). These writers also indicate the seasons of optimum occurrence of the striped and southern bluefin tunas in these waters, the position of the former, which is abundant from February to May, being more clear-cut. Serventy (1941*a*), Thompson (1943, p. 284), and Fowler and Serventy (1944) all state that these occurrences of striped tuna may be very large.

(*c*) *Australian " Salmon ".*—Within this area, shoals of Australian " salmon " were observed on only 6 of the 131 days of survey work by the *Warreen* (see Tables 22 and 23). During the general period of these investigations a fish cannery, depending to a large extent on " salmon " catches, was in operation in this region, and it is apparent that here, as indicated also for the New South Wales south coast, the *Warreen's* observations have no significant relationship to the actual occurrences of this species. No other ship log records of occurrences of Australian " salmon " have been received from this area.

(*d*) *Other Species.*—No pilchard shoals were found in this area during the *Warreen's* investigations, although the species has been reported there (St. Helens region, August to November 1924; see Blackburn 1941, p. 21). There is no evidence of eggs or larvae in the plankton of these waters (loc. cit., pp. 36-37), so the species must be rare. There are two records of anchovy shoals (August 1938, and May 1940, both identified from specimens), but this species also seems rare in the offshore waters (see also loc. cit., pp. 82, 85).

TABLE 23

NORTH-EASTERN TASMANIA

Records of Australian "Salmon" shoals (*Warreen*)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1938	*	*	*	*					*			*	
1939		*	*	1	*		*						1
1940	*		*	*						*	*		
1941		*				1	*	*	*	*	*	*	1
1942	*	*		4		*	*	*	*	*	*	*	4
Total				5		1							6

* Indicates months in which no work was done in the area.

There are no definite records in these data of horse-mackerel shoals from this area, although one occurrence seen in April 1939 was thought to be of this species. The fish occurs there, however, having been recognized on several occasions amongst the stomach contents of southern bluefin tuna, and there is more recent evidence from aerial survey work. However, it is less common here as a surface shoaling fish than it is further south (see below). The failure of the *Warreen* to locate shoals was probably due to her offshore position (see p. 46).

7. *South-eastern Tasmania*

(*a*) *General.*—The area extends from Cape Lodi to South East Cape, and includes the former. Localities mentioned in this area not shown in Figure 1 are marked on Figure 3.

There are records of 501 boat-days for this area to the end of December 1944. The survey work is still continuing, but the data for quantitative analysis for 1945 are thought to be less satisfactory than those for the earlier period. The *Liawenee* (Tasmanian Government vessel) worked 159 of these days (1944); the *Warreen* 153 (1938-42); the *Mary* (private vessel) 131 (1943-44); the *Arcadiar* (Tasmanian Government) 32 (1942-43); the *Jester* (private) 17 (1942-43); the *Aralla* (Tasmanian Government) 5 (1942, 1944); and the *Legara* (private) 4 (1943). Records are also available for 16 days by the *Aralla* for

1942 and 1944. These were omitted from the analysis, since they all referred to one small area (the northern end of the D'Entrecasteaux Channel) which has been proved a poor area for pelagic fish shoals.

The area is regarded as distinct from the north-eastern sector by virtue of the fact that the principal shoaling species of that region, the striped tuna, is almost absent here (see Serventy 1941*a*, p. 39; 1941*b*, pp. 54-5); and because the shoals of horse-mackerel, which seem much less common in the north-east,

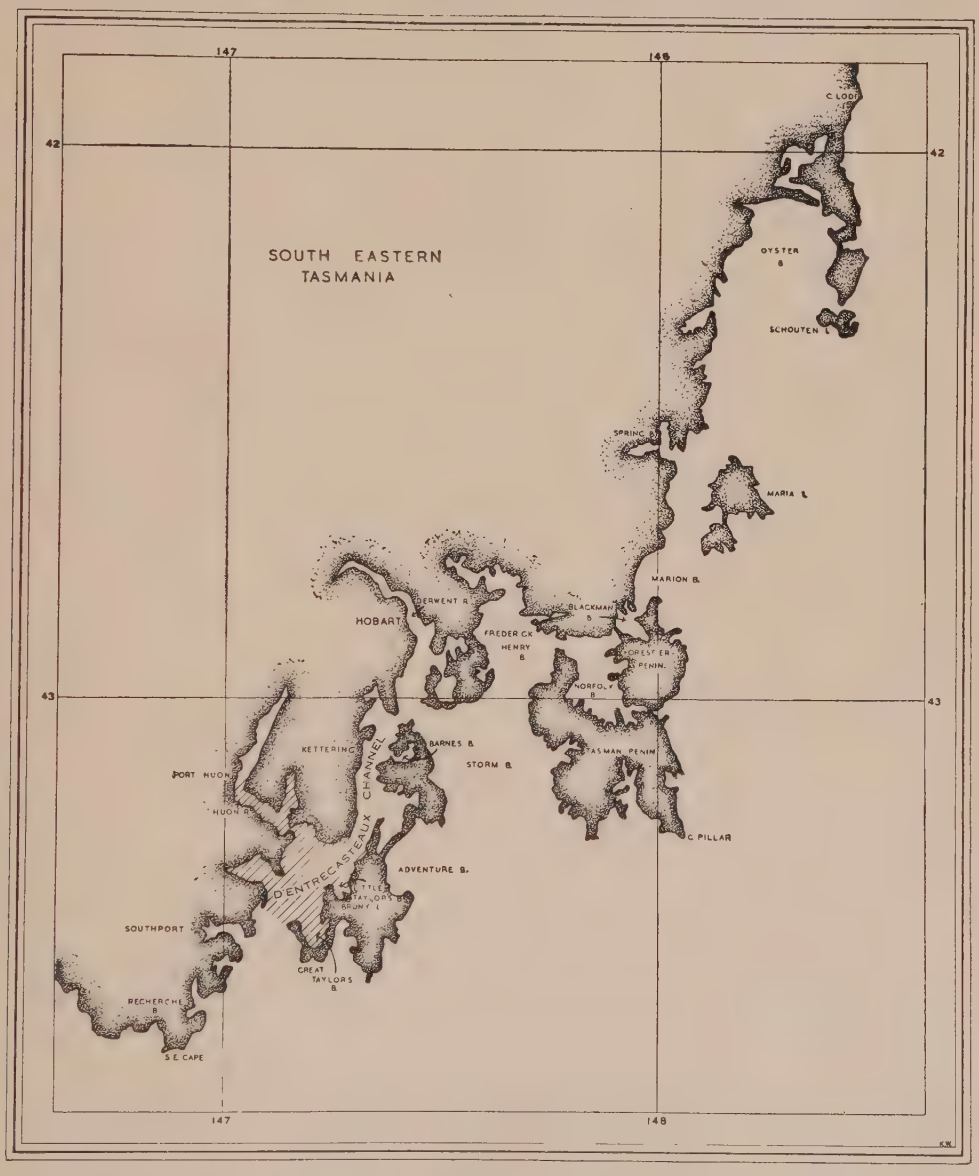

FIG. 3

South-eastern Tasmania, showing localities mentioned in the text. The south D'Entrecasteaux Channel sprat area is indicated by shading.

are usually a conspicuous feature of this south-eastern sector. Again, sprats (*Clupea bassensis*) have been found only in the south-east during the present investigations; although the species has been recorded from Flinders Island and the Tamar River (see Blackburn 1941, p. 54) and thus probably does shoal in the north-east and in Bass Strait at times*.

A good proportion of the above total of boat-days was spent in one particular area, the south end of the D'Entrecasteaux Channel, which experience has shown to be a special area for shoaling sprat occurrences. On the other hand, shoals of other species (especially horse-mackerel, not found at all in these investigations) do not seem common in this locality. It is therefore necessary to divide the records into two parts, those for the south Channel waters and those for the remainder of the south-eastern sector, and the latter are considered first.

The total number of boat-days referable to this main part of the area is 423, made up by: *Liawenee* 158 (1944), *Warreen* 130 (1938-42), *Mary* 111 (1943-44), *Arcadiar* 10 (1942-43), *Jester* 10 (1942-43) and *Legara* 4 (1943). This total is dissected month by month in Table 24. Every month of the year except one

TABLE 24

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTHERN CHANNEL WATERS

Summary of Observations, All Vessels, All Years, (Excluding Tunas)

Month	Total Days	Days Horse-mackerel Seen	%	Days "Salmon" Seen	%	Days Pilchard and Anchovy Seen*	%	Days Others Seen†	%	Days Horse-mackerel Fishable	%
Jan.	19			1	11·1						
Feb.	33	5	15·2	1	3·0			1	3·0	4	12·1
Mar.	62	18	29·0	4	6·5	2	3·2	1	1·6	9	14·5
April	59	18	30·5	6	10·2	2	3·4	1	1·7	12	20·3
May	88	24	29·5			2	2·3			19	21·6
June	62	9	14·5			2	3·2	3	4·8	6	9·7
July	38			1	2·6						
Aug.	9										
Sept.											
Oct.	23	1	4·3								
Nov.	18										
Dec.	22	3‡	13·6								
Total	423										

* One of the June occurrences was anchovy, the rest probably all pilchard.

† The February and April occurrences were barracouta, and one of the June occurrences was pearl fish (*Emmelichthys nitidus*); others consisted of unidentified "small fish," possibly including sprats.

‡ Identification doubtful, some or all of these shoals may not have been horse-mackerel.

* There is now every reason to suspect the recording of this species from the waters of South Australia, the only other region from which it has been listed (see Blackburn, loc. cit., pp. 53-54). The record is from Regan (1916 p. 5) who did not specify the locality precisely. From information kindly provided by Dr. Ethelwynn Treawavas, it appears that there are no specimens at the British Museum from any other region than Tasmania, and that Regan's words "South Australia" may have been intended to mean "Southern Australia."

(September, in which there was no work done) received attention on at least two occasions, and most months more frequently. The entire area was very thoroughly traversed several times, although the extreme southern portion of it (Southport and Recherche districts) received much less attention than the rest.

(*b*) *Horse-mackerel.*—This species, which is the cowanyoung of New South Wales, is generally known in Tasmania as " mackerel," and is hereafter referred to as such in this section of the discussion. It is a different fish from the true mackerel (*Pneumatophorus australasicus*).

It will be seen from Table 24 that, apart from a minor record for October and a few dubious ones for December, the season of occurrence of shoals is from February to June, with the three middle months most important. However, the data for January are rather scanty, and the possibility of the occurrence of mackerel shoals does not seem to be excluded; and indeed in January 1945 (data not included in these records), such shoals were found abundantly on one occasion on a cruise of 11 days. Some were also seen in January 1947. The season is therefore taken hereafter as from February to June, but it should be borne in mind that some fish are to be found in January. According to Johnston (1883, p. 119) mackerel shoals are most abundant from January to June; in another reference (1891, p. 25) he gives the season as January to April†

It is interesting to tabulate the mackerel occurrences as reported by the three vessels, viz. the *Liawenee, Warreen,* and *Mary,* which made most of the observations, and all of which spent comparable periods of time on this work. The results are presented in Table 25 on the same lines as for the previous table.

TABLE 25

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Observations on Mackerel Shoals

Month	*Warreen* (1938–42)			*Mary* (1943–44)			*Liawenee* (1944)		
	Total Days	Days Mackerel	%	Total Days	Days Mackerel	%	Total Days	Days Mackerel	%
January	9								
February	4			16	4	25·0	13	1	7·7
March	16	2	12·5	17	4	23·5	17	6	35·3
April	13	4	30·8	18	5	27·8	19	7	36·8
May	39	10	25·6	28	11	39·3	21	3	14·3
June	24	5	20·8	17	3	17·6	21	1	4·8
July	4			15			19		
August	4						5		
September									
October	9						11		
November	2						16		
December	6						16	3*	18·8
Total	130			111			158		

* Dubious, see footnote to Table 24.

† As already mentioned, there is some commercial fishery for this species, and in 1944 the bulk of the catch was made between February and May, inclusive. This is an inshore fishery, based mainly on the Forestier and Tasman Peninsulas. Production in 1944 (the best year) was of the order of 135,000 lb.

The comparison is fair, being best for the month of April. On the whole the records of all three craft convey a similar picture of general duration of the seasonal occurrence and order of abundance of shoals. For the season February to June taken as a whole, the similarity in the findings is more obvious, and this comparison is made in Table 26.

TABLE 26

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Observations on mackerel shoals, February-June

Craft	Total Days	Days Mackerel Seen	%
Warreen (1938–42)	96	21	21·9
Mary (1943–44)	96	27	28·1
Liawenee (1944)	91	18	19·8
Total	283	66	23·3

It is unnecessary to compute χ^2 to realize that there are no significant differences between the positions as discovered by these three vessels. These data support the suggestion that was made previously, that the past performance of vessels in searching for fish shoals may give useful indications as to what other boats, including commercially operating units, can be expected to achieve in the future.

For consideration of the question of annual abundance during the optimum season, the combined data for all vessels are summarized in Table 27.

TABLE 27

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Mackerel Shoals, February-June

Year	Total Days	Days Fish Seen	Days Fish not Seen	Days Fish Seen (%)	χ^2
1938	11	1 (2·68)	10 (8·32)	9·09	1·392
1939	11	2 (2·68)	9 (8·32)	18·18	0·229
1940	19	1 (4·62)	18 (14·38)	5·26	3·747
1941	40	11 (9·74)	29 (30·26)	27·50	0·215
1942	25	9 (6·08)	16 (18·92)	36·00	1·853
1943	51	16 (12·41)	35 (38·59)	31·37	1·373
1944	147	34 (35·78)	113 (111·22)	23·13	0·117
Total	304	74 (73·99)	230 (230·01)	24·34	8·926

In this case, $\chi^2 = 8.926$, and for $df = 6$, $P > 10$ per cent., nearly 20 per cent., non-significant. The conclusion is that there were no annual fluctuations of importance, and the abundance of shoals in this season, in all these years, can thus be described by the overall index of 24 per cent. of days.

It will have been noticed that Table 24 included, in addition to the particulars of mackerel shoals generally, a column tabulating records of "fishable" mackerel shoals. Owing to the fact that the mackerel has been the object of much more intensive pelagic net fishing experiments than any other species in south-eastern Australia, it has been possible, from the experience of such work, to erect criteria for distinguishing potentially "fishable" from "unfishable" shoals, the former being all those which seemed suitable for purse-seining. The criteria by which fishable shoals are distinguished vary according to circumstances, but calm weather is the main consideration, no shoal being suitable for purse-seining operations if there is anything more than a light wind, sea or swell; although, indeed, relatively few mackerel shoals appear under any but fine conditions. Other considerations would be the size and number of the shoals, their mobility (quiet shoals being preferable), and various features of their location. Regarding the last, shoals on a lee shore, or in a fast flowing tide, or in water shallower than the depth of the net (unless the bottom is smooth), or travelling in the same direction as the wind, would be unsuitable for this kind of work. Naturally there were cases where doubt was felt whether the shoals were to be classed as fishable or otherwise. These mostly referred to those recorded prior to 1942, when the above criteria were first fully recognized. There was generally sufficient indication in the logbook to leave little doubt, and most of the observations from 1942 onwards were made by one of the authors.

It appears from Table 24 that the abundance of such fishable shoals parallels that of the shoals generally. It is now of interest to obtain a percentage index which can be taken to represent the position each year. The data are summarized in Table 28.

TABLE 28

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Mackerel Shoals, Fishable, February-June

Year	Total Days	Days Fish Seen and Fishable	Days Fish not Seen or not Fishable	Days Fish Seen and Fishable (%)	χ^2
1938	11	1 (1·81)	10 (9·19)	9·09	0·433
1939	11	1 (1·81)	10 (9·19)	9·09	0·433
1940	19	(3·13)	19 (15·87)		3·747
1941	40	9 (6·58)	31 (33·42)	22·50	1·065
1942	25	5 (4·11)	20 (20·89)	20·00	0·231
1943	51	13 (9·39)	38 (42·61)	25·49	3·032
1944	147	21 (24·18)	126 (122·82)	14·29	0·500
Total	304	50 (50·01)	254 (253·99)	16·45	9·441

Here $\chi^2 = 9.441$, and for $df = 6$, $P > 10$ per cent. < 20 per cent., non-significant. The conclusion is the same as in Table 27.

It could thus perhaps be said that mackerel shoals are liable to be encountered, on average, on 24 per cent. of all days spent at sea in this sector, during the season February to June; that on about two-thirds of these occasions the conditions would permit the safe setting of a purse-seine net; and that with proper boat and gear and skilled crew there would be a high expectation of making a catch. However, there are some further considerations to be borne in mind.

It will be noticed, from Tables 27 and 28, that even though the χ^2 test provides no clear evidence of significant fluctuation from year to year, the abundance indices for the years 1938, 1939, and 1940 are all substantially lower than for any of the four subsequent years. This is probably due to the fact that these early observations were all made by the *Warreen,* which was not then specifically seeking mackerel shoals, being mainly engaged in seeking tuna shoals which it was thought might be found in this sector. Her work on this coast was, therefore, then largely done in a zone of water about two miles and upwards offshore, where the tuna shoals were mostly found in the waters off the south coast of New South Wales and off north-eastern Tasmania. It has already been shown that this accounts for the extremely scanty records of " salmon " shoals in the abovementioned areas, this species being found typically very close to the shore; and since the mackerel shoals are found, on the whole, fairly close inshore also (not generally as near in as " salmon," but mostly within a mile of land, and not often more than three miles off), it seems clear that they would not often have been noticed by the *Warreen* prior to 1941. By 1941 it had become apparent that surface tuna shoals were not a feature of the south-eastern Tasmanian region, but that mackerel shoals were, and the zone of investigation was shifted closer inshore.

It follows that for greater precision the test should be applied to data of the 1941 and subsequent seasons only, both for shoals generally and for fishable shoals. The data and the tests are summarized in Tables 29 and 30.

TABLE 29

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Mackerel Shoals, February-June

Year	Total Days	Days Fish Seen	Days Fish not Seen	Days Fish Seen (%)	χ^2
1941	40	11 (10·65)	29 (29·35)	27·50	0·016
1942	25	9 (6·66)	16 (18·34)	36·00	1·121
1943	51	16 (13·58)	35 (37·42)	31·37	0·588
1944	147	34 (39·13)	113 (107·87)	23·13	0·917
Total	263	70 (70·02)	193 (192·98)	26·62	2·642

Here $\chi^2 = 2{\cdot}642$, and for $df = 3$, $P > 30$ per cent., nearly 50 per cent., non-significant. There is now much more homogeneity in the series, and the abundance index is slightly higher (see Table 27).

TABLE 30

SOUTH-EASTERN TASMANIA, EXCLUDING SOUTH CHANNEL WATERS

Mackerel shoals, fishable, February-June

Year	Total Days	Days Fish Seen and Fishable	Days Fish not Seen or not Fishable	Days Fish Seen and Fishable (%)	χ^2
1941	40	9 (7·30)	31 (32·70)	22·50	0·484
1942	25	5 (4·56)	20 (20·44)	20·00	0·051
1943	51	13 (9·31)	38 (41·69)	25·49	1·790
1944	147	21 (26·83)	126 (120·17)	14·29	1·550
Total	263	48 (48·00)	215 (215·00)	18·25	3·875

In this case $\chi^2 = 3{\cdot}875$, and for $df = 3$, $P > 20$ per cent., nearly 30 per cent. non-significant. There is again more homogeneity and a slightly higher abundance index (see Table 28).

It can therefore be concluded that mackerel were at about the same level of abundance in at least four (and probably more) successive years at this season, a level such that shoals would be found by a vessel on an average of about 27 per cent. of days spent at sea, and fishable shoals on an average of two-thirds of these occasions, i.e. 18 per cent. of days at sea. From this evidence, there would seem to be a high expectation of a boat finding shoals as frequently as this in any year over this season. This is indeed probably a fair conclusion, but there may be occasional exceptions, such as apparently occurred in 1946.

As mentioned above, similar data for 1945, 1946, and 1947 have not been included in the foregoing tabulations because of doubts as to whether the 1945 records, at any rate, were comparable in reliability with those for previous years. However, it is sufficient to describe briefly the general findings in those three seasons. In 1945, the survey work was done in February, March, and early April only, when the shoals, especially those regarded as fishable, were scarcer than usual at that time. This, however, was mainly due to rather poor weather, and the fish were found on the few occasions when calm conditions prevailed, indicating that they were present as usual. Shoals were also noticed during aerial surveys at this time. As the weather improved through April and May shoals were found more frequently, and on a total number of occasions reasonably comparable with that for other years at the same time; and it is extremely probable that the position for the 1945 season as a whole was not very different from that in preceding years. However, in 1946 the conditions were rather peculiar. In this season shoals were noticed during February and early March, at about the usual level of abundance for this period; but later

there was fairly consistent unfavorable weather (fresh breezes and seas, overcast and rather cold days, with frequent rains) and, again apparently as a result of this (since fish had been found earlier, and continued to be found on the rare days of fine weather), there were few shoals, certainly very few fishable shoals, encountered. The records of this season, if tabulated and submitted with the previous data to the χ^2 test, would thus probably indicate at least a slight adverse fluctuation of abundance of shoals, though not necessarily (and not probably) of actual abundance of fish on the coast. Thus, although the circumstances in this 1946 season were from all evidences distinctly unusual, it must be borne in mind that there can be such exceptions to the general position of a consistent shoals abundance level as indicated by the foregoing tables and discussion. In the 1947 season the occurrences of mackerel shoals were again on the normal scale.

On most of the days on which mackerel shoals were seen, more than one shoal was observed. Out of the total of 74 days on which fish were seen, in the season February to June of the years 1938 to 1944 inclusive, there were 11 on which only single shoals, and 63 on which two or more shoals, were seen.

On the question of the identification of mackerel shoals, and in particular the distinction from the very similar " salmon " shoals, it is possible that there are included in the above tabulations a few individual cases of mackerel shoals being identified as " salmon " shoals, or *vice versa*. It is felt, however, that such errors are extremely few. Most Tasmanian fishermen recognize certain criteria for distinguishing between the two species, and similar criteria were independently set up from their own experience by the Organization's officers, and proved correct in almost every case where identification was possible from captured fish. There was hardly ever any doubt whether a given concentration of mackerel should be recorded as a true shoal or not.

Mackerel shoals are to be found in almost all parts of the south-eastern Tasmanian sector, except the relatively land-locked waters of the Derwent estuary, D'Entrecasteaux Channel, and Frederick Henry, Norfolk, and Blackman's Bays. To the extent that there was some time spent (on passage, mostly) by the survey vessels in these areas, the above-mentioned quantity indices may be considered slightly on the low side. Except for the Southport-Recherche area in which no shoals were noticed (although very little time was spent there, and there is definite evidence from other sources* that the fish occur in shoals in this district), the expectation of finding shoals at any particular time is no greater at one place than at another. Thus, although the *Liawenee* spent most of her time in one particular area (Marion Bay, where she was mainly engaged in Danish-seining), her opportunities for observing such shoals were at least almost as great as those of any of the other vessels, and this seems to be confirmed by the evidence of Tables 25 and 26. However, this vessel covered almost the entire sector on several occasions.

Plate 2 illustrates typical mackerel shoals from these waters.

(*c*) *Australian " Salmon "*.—Despite the large number of boat-days spent in this area, in which a significant proportion of the total Tasmanian catch of Australian " salmon " is produced, shoals of these fish were recorded on 15 of 501 days (i.e. including the south Channel waters, for which there were two

* Including an aerial survey in March 1943.

occurrences). From 1938 to 1941, the *Warreen's* activities kept her outside the normal zone of occurrence of the species, and during that period shoals were recorded only on 3 days. From 1942 to 1944 the operations of the *Warreen* and other vessels yielded records of shoals observed on 12 days (see Table 31, also Tables 24 and 32). During this latter period, the vessels operated close to the shore, in search of shoals of horse-mackerel†. In respect of boat-days the two periods were fairly comparable, and yet the number of recorded occurrences of "salmon" shoals did not increase to the level which might have been expected. Certainly the recording of shoals on only about 5 per cent. of days of observation would not suggest the possibility of a fishery of even the modest proportions of the existing Australian "salmon" fishery of south-eastern Tasmania, i.e. of the order of 35 tons output per annum.

This paucity of records may be explained, in part, by reference to the observed habits of the species within the area. In southern Tasmanian waters the Australian "salmon" does not appear to form the large shoals characteristic of the waters of the eastern Victorian and southern New South Wales coasts. Moreover the fish do not appear to surface freely and are, from vantage points on the beaches, more readily detected by colour than by surface ruffling. Thus it is possible that the vessels failed to detect shoals which might easily have been seen from the shore or from the air. However, other information to hand suggests that the Australian "salmon" is not a plentiful species in this area.

TABLE 31

SOUTH-EASTERN TASMANIA, ALL WATERS

Records of Australian "Salmon" Shoals (all Vessels)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1938	*	*	*	*			*	*	*		*	*	
1939		*	*		*		*	*	*				
1940	*	1	*	*					*	*	*		1
1941	1	*		1			*	*	*	*	*	*	2
1942	*	*	1	2		1			*				4
1943	*		3	1			1	*	*	*	*	*	5
1944	*		1	2					*				3
Total	1	1	5	6		1	1		*				15

* Months no work was done on the coast.

† The statement here that the *Warreen* operated outside the "salmon" occurrence zone in 1941 does not conflict with the earlier statement that she was operating within the mackerel occurrence zone in that year. The position is actually that prior to 1941 the *Warreen* operated outside even the mackerel zone for the most part, in 1941 she worked inside it but not mostly within the "salmon" zone, while in 1942 and subsequent years most of the work was done closer inshore still, largely in the "salmon" zone.

(*d*) *Pilchards* (*and Anchovies*).—Pilchard specimens (from beach-seine catches, barracouta stomachs, &c.) have been obtained from various places in this region on a few occasions during these investigations, from January to July, and there were previous records also (including one for Storm Bay in August 1922, see Blackburn 1941, p. 21). However the species seems to be rare, and there were no eggs or larvae in the plankton catches (loc. cit., pp. 36-37). Table 24 shows that a few shoals of pilchards or presumed pilchards (all daylight occurrences) have been recorded from March to June. On one of these occasions reasonably certain identification was afforded by specimens caught in a beach-seine nearby, but otherwise the shoals were only identified from their likeness to the pilchard shoals of New South Wales; although the sprat has a very similar shoaling habit, and there is thus some possibility of error on this account. The areas for which the shoals were recorded ranged between Cape Pillar and Oyster Bay, and this is identical with the range for which all the above pilchard specimens have been obtained at the same general season, except in one record. This was of a small sample obtained in the south part of the D'Entrecasteaux Channel, in July 1945.

Shoals of anchovies, identified from specimens captured nearby, were seen once in June 1940, at Oyster Bay. Otherwise only a few isolated specimens were caught in the offshore waters in this area, and as there was no trace of larvae in the offshore plankton (loc. cit., p. 85), it is thought that in this region, as in many others, the species is not a conspicuous constituent of the offshore pelagic fish fauna. In the more enclosed waters of the D'Entrecasteaux Channel the fish appears to be more abundant, whereas in the bays and estuaries proper it is (as in other regions) considerably more abundant at times.

(*e*) *Tunas.*—According to Serventy (1941*a*; 1941*b*) and Fowler and Serventy (1944, pp. 2-3), three species are known from this area—the southern bluefin, albacore, and striped tuna. Only the first-named appears to be of any considerable importance, and the last is rarely met with in these waters. The optimum season for southern bluefin is said to be from November to May and June. This species may vary somewhat in abundance from year to year, as shown by Serventy (1947, pp. 141-44).

(*f*) *Sprats.*—The sprat region in the south of D'Entrecasteaux Channel includes the Huon estuary up to Port Huon, and Little and Great Taylor's Bays, and adjacent waters. These are the only areas in which sprat shoals have been positively recorded by any vessels participating in the Organization's surveys.

However, as remarked before, the sprat is known to occur as far north and west as Flinders Island and the Tamar; and in the present investigations odd specimens have also been obtained (*ex* stomachs of barracouta, southern bluefin tuna, tiger flathead, and rock cod) from other south-eastern localities in the warmer months of the year (October to May), mostly in various parts of Storm Bay, but also at Cape Pillar, Marion Bay, and Spring Bay. A shoal drove into Kettering in March 1944, and was netted there by fishermen. Shoals which were almost certainly of this species were noticed at Barnes Bay in May 1944, at Spring Bay in March 1945, and in Frederick Henry Bay in March 1945 and May 1946. There are also on record (see footnote to Table 24) from the survey vessels themselves three shoals of unidentified small fish, some or all of

which may have been sprats; the March occurrence was off Barnes Bay and the two in June were from Storm Bay. There are other records not so reliable, but generally confirming the picture already drawn. One has the definite impression that the sprat is more plentiful in the waters of the Storm Bay system than in those further north, in which it seems to be largely replaced (see above) by the pilchard; however there is certainly some considerable overlapping of the two species.

Records are available for 86 boat-days for the south Channel waters up to the end of December 1944, made up by: *Warreen* 28 (1940-42), *Arcadiar* 23 (1942-43), *Mary* 20 (1943-44), *Jester* 7 (1943), *Aralla* 5 (1942, 1944), and *Liawenee* 3 (1944). This grant total, and the totals from the *Warreen, Arcadiar,* and *Liawenee,* add up, when combined with those already given for the rest of the south-eastern sector, to more than the figures given previously for the whole of the sector. This is on account of 8 days (*Warreen* 5, *Liawenee* 2, *Arcadiar* 1) spent partly in and partly out of this area, and which have therefore been included in both compilations. There was also some survey work done in 1945, 1946, and 1947, but by private operators only, and while the general results are known, the available records are probably not quite comparable with the earlier information as regards suitability for quantitative analysis. Generally speaking these later results were in line with those for the previous years. The total of 86 boat-days is dissected by months in Table 32.

TABLE 32

SOUTH D'ENTRECASTEAUX CHANNEL WATERS

Summary of Observations, all Vessels, all Years

Month	Total Days	Days Sprats* Seen	%	Days "Salmon"* Seen	%	Days Sprats Fishable	%
January							
February	3						
March	18	2	11·1	1	5·5	1	5·6
April	15	2	13·3				
May	26	7	26·9			6	23·1
June	14	2	14·3	1	7·1	1	7·1
July	2						
August	5	1	20·0				
September							
October							
November	1						
December	2						
Total	86						

* No other species were observed shoaling at the surface.

The observations for this sub-sector are not as full or complete as for most of the other areas so far considered. However, in the period March to June there have been frequent cruises in this area, which, being small, can be fairly thoroughly searched in a short time.

It is thus difficult to define the sprat shoaling season as precisely as has been done for most of the species already discussed. Obviously the season covers the period from March through June, and it may extend to August or

later. On the other hand, the paucity of data for the months before March leaves the question open as to whether the season of sprat shoals, of the order of abundance found from March to June, does not begin earlier. There are consistent reports from fishermen of shoals, both in this region and elsewhere (north end of the Channel, Storm Bay, and even Spring Bay), in December, November, and even late October, and thus (bearing in mind also the evidence of specimens mentioned above) it is not doubted that some shoals are to be found in these months, and possibly all the year round. According to Johnston (1891, p. 27) the shoals are most abundant from August to November. However the writer responsible for the sprat investigations (Blackburn) has the very strong impression that the shoals are not as abundant before March as during and after it, in the Channel waters at any rate, and that the optimum season begins about that month. This impression is largely based on the fact that private operators with long experience of the area have so far confined their sprat-seeking activities to this later period. It is less clear when the season ends because of the scanty data for the period after June, but the period March to June inclusive can meantime be taken as the optimum season. This is probably fairly accurate, because the weather at this season is generally finer than over the rest of the year, and sprats surface best under calm conditions.

To aid the consideration of the year-by-year abundance of shoals during what is regarded as the optimum season, the combined data for all vessels are summarized in Table 33.

TABLE 33

SOUTH D'ENTRECASTEAUX CHANNEL WATERS

Sprat shoals, March-June

Year	Total Days	Days Fish Seen	Days Fish not Seen	Days Fish Seen (%)	χ^2
1940	7	3 (1·25)	4 (5·75)	42·86	2·983
1941	19	2 (3·38)	17 (15·62)	10·53	0·685
1942	14	5 (2·49)	9 (11·51)	35·71	3·077
1943	26	3 (4·63)	23 (21·37)	11·54	0·698
1944	7	(1·25)	7 (5·75)		1·520
Total	73	13 (13·00)	60 (60·00)	17·81	8·963

In this case $\chi^2 = 8.963$, and for $df = 4$, $P > 5$ per cent., but well below 10 per cent. This just passes the conventional level of significance (see also Appendix 1) but the position is borderline, and it would be most appropriate to say that, while the overall percentage of 18 per cent. days of observations gives some indication of the abundance of shoals from year to year, the species is subject to slight annual fluctuations in abundance, at least as far as surface shoals are concerned.

In the same way as for horse-mackerel, a distinction has been made between "fishable" and other shoals, as already indicated in Table 32. The position is summarized for the different years in Table 34.

TABLE 34

SOUTH D'ENTRECASTEAUX CHANNEL WATERS

Sprat shoals, fishable, March-June

Year	Total Days	Days Fish Seen and Fishable	Days Fish not Seen or not Fishable	Days Fish Seen and Fishable (%)	χ^2
1940	7	2 (0·77)	5 (6·23)	28·57	2·208
1941	19	2 (2·08)	17 (16·92)	10·53	0·003
1942	14	3 (1·53)	11 (12·47)	21·43	1·585
1943	26	1 (2·85)	25 (23·15)	3·85	1·349
1944	7	(0·77)	7 (6·23)		0·865
Total	73	8 (8·00)	65 (65·00)	10·96	6·010

Here $\chi^2 = 6{\cdot}010$, and for $df = 4$, $P > 10$ per cent., nearly 20 per cent. It could be expected that fishable sprat shoals would be found yearly on about 11 per cent. of days spent at this season in this area.

However this figure for "fishable" sprat shoals is much less informative than the corresponding index for fishable "mackerel" shoals. These sprat shoals have also been the subject of some fairly intensive surface net fishing experiments, which have enabled those associated with the work to establish criteria for distinguishing fishable from unfishable shoals, in respect of such nets. However, these criteria were not on the whole so clear as those employed for mackerel. Experiments have shown that the lampara net, which was the type mainly employed, may vary considerably in performance; because of its large-meshed wings (which permit fast hauling) the fish have a chance to escape even after being encircled, the escapement depending mainly on the speed with which the net is hauled. There have been occasions when the net was shot around good shoals and yet few or no fish captured. So all that can be said is that the shoals regarded here as fishable were those which by virtue of their size or number, quietness (sprat shoals are on the whole quieter in their behaviour at the surface than those of any other pelagic species in south-eastern Australia) and location, and the weather and sea conditions under which they were found, would be regarded as warranting a shot with the lampara net.

On the other hand the presence of sprat concentrations can at times be inferred with virtual certainty from the diving of gannets, and on two occasions sets of the lampara net around such places resulted in significant hauls. As mentioned earier, such concentrations not actually seen have not been included in these tabulations, so the above-mentioned quantity index in respect of

fishable shoals does not say the last word in respect of opportunities for surface fishing operations. To an extent which is hard to evaluate, the outlook for such operations is better than indicated by that figure. Also, a boat attracted to an area by birds working will at times discover true surface shoals there.

Sprat shoals have the same very characteristic shoaling appearance as those of pilchards, i.e. surface " flipping " or pattering (Plate 1, Fig. 2) and can easily be distinguished from shoals of all other fish. There may have been some slight confusion between sprat and pilchard shoals in other parts of the south-eastern Tasmanian sector (see above), but not in these south Channel waters, where nearly all the shoals were sampled and identified from the samples, and where pilchards seem extremely rare.

On most occasions on which sprat shoals were found, there were more than one. Out of the total of 13 days on which fish were seen, in the season March to June, there were 3 days when single shoals were seen and 10 days when more were seen.

8. *Tasmania, West Coast*

This area includes the waters between South-East Cape in the south and Cape Grim in the north.

The data are extremely meagre, comprising records of 4 days only spent here by the *Warreen,* 2 days in May 1938 (southern part only), and 2 days in June 1940 (entire area). No fish shoals were seen on either occasion. However, some shoals of horse-mackerel were noticed from the air in March 1943, and at about the same time in 1945.

9. *Bass Strait*

This area includes the waters of the entire north coast of Tasmania, from Cape Grim to Cape Naturaliste, and of the western shores of the Furneaux Islands; also the Strait itself, but not the waters of the Victorian coast.

The data are again inadequate, and no conclusions can be drawn. The *Warreen* (1938-41) spent a total of 35 days, 20 days in the waters just west of the Furneaux Group, 10 days between the Furneaux Group and Wilson's Promontory (mainly on passage), 3 days on a single survey trip along the Tasmanian north coast (June 1940) and 2 elsewhere in the Strait. No fish shoals were seen.

Relatively few reports of shoaling pelagic fish have been received from any part of this sector. Australian " salmon " occur along the shore, and are fished to some extent. Fishermen at Stanley reported shoals of some small pelagic fish in the summer of 1941-42. Other north coast operators have spoken of shoals of small fish (said to be anchovies) from about July to September, and possibly at other times, in various parts of Bass Strait, including near King Island. Plankton hauls made in the mid-Strait during April 1939, indicated some occurrence of pilchard and anchovy in that area (Blackburn 1941, pp. 36, 85).

10. *Victoria*

(*a*) *General.*—The area includes the waters of the entire coastline of Victoria, from (but not including) Gabo Island to the South Australian border.

The data from the boat surveys of the Council are meagre, and no conclusions can be drawn from them. There were 34 days spent, all by the *Warreen* (1938-41). Of these, 8 days refer to west of Port Phillip Bay (February, March, and December 1939); 11 days refer to between Port Phillip Bay and Wilson's Promontory (May, June, and July 1938, and February, November, and December 1939); and 15 days refer to north and east of Wilson's Promontory (August and November 1938, January, February, and November 1939, July, 1940, and June 1941). The only shoal of fish seen was one of pilchards, off Little Rame Head (near the New South Wales border) in June 1941.

However there is some general information regarding Victorian pelagic fish occurrences that has been gathered by the Organization's investigators from their association with fishermen and the markets. This is not of a really quantitative character, but it is summarized here for completeness.

(*b*) *Australian "Salmon".*—Until quite recently second in importance only to barracouta in the Victorian catch, the Australian "salmon" was the basis of a firmly established fishery, particularly along the eastern coast.

This fishery depends upon shoals travelling close to the beaches, and during the period of the *Wareen's* activities along the eastern coast of Victoria the annual catch averaged about 840 tons (1938-41).

Although partially seasonal, the catch is maintained at a fairly high level throughout the year, and it is an interesting commentary upon the extreme narrowness of the zone of occurrence of this species that the *Warreen* failed to record any shoals during the period spent along this coast.

(*c*) *Pilchards and Anchovies.*—Both these species occur in Port Phillip Bay, and support a small fishery, being in limited demand for fish paste manufacture, salting, and bait for anglers. The pilchard is mainly caught between October and May, but the anchovy is also available in large numbers in the winter months. The anchovy (called "whitebait" by many fishermen) is the main species taken. Unlike the pilchard it does not seem subject to annual fluctuations.

In most years outside Lakes Entrance pilchards and anchovies shoal between April and October. For the Wilson's Promontory area, pilchard shoals were reported, in large occurrences at times, from the middle of 1943 to January 1944. In the offing of Westernport Bay, both pilchards and anchovies were very abundant between about July and September 1945; pilchard shoals are also said to be seen commonly in the autumn months. Off Port Fairy, shoals of anchovy were seen at various times between May and October in 1944 and 1945, and specimens were obtained (*ex* barracouta) at these and other periods. Nearly all reports were confirmed in part at least by obtaining specimens.

The general picture of occurrences of these species in respect to optimum seasons etc. is apparently an involved one, but clarification may be expected when current studies on their biology in this region are further advanced; there

were also many very puzzling features about the occurrences of pilchards in New South Wales waters until an age-study had been carried out upon those fish. It has already been pointed out (Blackburn 1941, pp. 7, 30, 43) that the pilchards of Victoria, South Australia, and perhaps Tasmania are probably a group (or series of groups) distinct from those of Queensland and New South Wales, being mainly summer and early autumn spawners instead of mainly winter spawners. Additional evidence in support of this distinction is now becoming available.

(*d*) *Tunas.*—The tunas of Victorian waters have been discussed by Serventy (1941*b*; see also 1941*a*). There are five recorded species of which only one, the southern bluefin, " is really abundant and widespread in Victoria ". According to Fowler and Serventy (1944, p. 2), the optimum season for this species is from about November to May.

(*e*) *Horse-mackerel.*—This species, also largely known as " mackerel ", is apparently moderately plentiful in Port Phillip Bay in the springtime. Some shoals of what was probably this form were noted off Port Fairy in January and March 1945, but such occurrences are not common there.

11. *South Australia*

(*a*) *General.*—The area extends from the Victorian border to Coffin's Bay, the most westerly point reached in the Organization's boat surveys. (Some aerial reconnaissance has been carried out further to the west.)*

The data available from the *Warren's* records are inadequate, since there were only 31 days spent there, all in the warmer months of 1939 (17 days in February and March, 14 days in December). War conditions militated against any more thorough subsequent work.* Actually there was a good deal of additional later survey work carried out in various parts of this area from smaller craft, but the records did not seem to lend themselves readily to quantitative analysis in respect of occurrences of shoals. Some indication of the general results is given in a separate paper under this cover, at the end of the present report (see p. 72).

(*b*) *Tunas.*—The southern bluefin tuna is the only species known from this area. Serventy (1941*a*, esp. pp. 30-31) gives particulars of seasonal occurrences, but Fowler and Serventy (1944, p. 3) state more briefly that: " The season of occurrence appears to be during the summer and autumn ".

(*c*) *Pilchards (and Anchovies).*—Pilchard shoals were seen twice during the *Warreen's* surveys, once near Port Lincoln and once off Cape Borda, both in February 1939, and both by day. The species was identified by its general shoaling character, and specimens obtained from the stomachs of tuna. However, there was evidence (from tuna stomachs) that these fish were more or less abundant below the surface, possibly in loose concentrations, over almost the whole general area of these eastern South Australian waters during February and March 1939, and over a more restricted area (east coast of St. Vincent's Gulf, and Backstairs Passage) in December of that year (see Blackburn 1941, pp. 30-31). Also, there was evidence of abundance of eggs and larvae at these

* See footnote on p. 57.

times from plankton hauls, especially in February and March, indicating the presence of spawning fish on a scale similar to that in New South Wales waters in the winter (loc. cit. p. 37). The private vessel *Corwa* found (and made catches from) some shoals of pilchards in these waters in the early part of 1940, mainly at Coffin's Bay, in March (loc. cit. pp. 46, 119). The general picture is one of reasonable abundance of fish in the summer and early autumn, but the matter warrants much more attention over the whole of the year, and the survey should also be extended further westward.*

Odd specimens of anchovy were also obtained, *ex* bluefin tuna, and there was some occurrence of eggs and larvae in the plankton in the same offshore waters at the same period as for the pilchard (loc. cit., pp. 83, 86, 87). Anchovies were reported to be abundant in Cowell Harbour in July 1941.

Some reference is made to the blue sprat (*Stolephorus robustus*), another clupeoid species from these waters, in the separate paper under this cover already mentioned. This form is known from almost all Australian waters south of the Tropic, and apparently from some tropical waters also, but has not been noticed in any other area as a very significant species in the more offshore waters (see loc. cit., pp. 60-62).

(*d*) *Australian "Salmon".*—The *Warreen's* logs contain no record of observations of this species in South Australia, although here, as in Victoria, it forms a significant part of the State's fish production. As indicated elsewhere, no significance can be attached to the failure of the *Warreen* to record the occurrence of "salmon" shoals.

IV. Discussion.

(*a*) *General Remarks on Occurrences*

The foregoing results show that pelagic fish occurrences are not uniform over the south-eastern area, and that they provide a fairly clear basis for its subdivision. Proceeding southwards and westwards, there is firstly the New South Wales north coast (with which might perhaps be united, as far as present indications go, the coast of Queensland south of the Tropic), in waters of which the only species of first-class importance is the pilchard; "salmon" and southern bluefin tuna are unimportant. Then follows the New South Wales south coast region with a seemingly different population of pilchards; "salmon" and southern bluefin well represented; striped tuna increasing in importance, and some other tunas of the previous region less important. North-eastern Tasmania presents a different facies again, comparable with the last-mentioned in respect of important occurrences of "salmon", and with the striped tuna of greater importance than southern bluefin; but pilchards here are quite rare. South-eastern Tasmania is perhaps more distinct than any other area; the principal shoaling species is the horse-mackerel, striped tuna as well as pilchards are rare, "salmon" is probably less abundant than further north, and there is in places another quite different species, the sprat. Nothing much is known about occurrences in western or northern Tasmanian waters. The Victorian area as a

* The *Warreen* resumed work in this sector in autumn 1947; pilchard shoals were found abundantly off the north coast of Kangaroo I., and along much of the west coast of Eyre's Peninsula.

whole is distinct from the adjoining New South Wales coast region, in that the pilchard population is different and the striped tuna of very much less importance than the southern bluefin, although "salmon" are plentiful. Possibly this region could be subdivided, and Serventy (1941*b*, p. 51) has indicated that for southern bluefin there are probably separate eastern and western stocks with affinities to those of New South Wales-Tasmania and South Australia respectively. Finally, the eastern parts (and probably the whole) of the South Australian waters are rather like those of Victoria in respect to similarity of pilchard population, the occurrence of southern bluefin as the predominant (in fact the only) tuna species, and of "salmon" in appreciable quantities.*

The barracouta is not discussed in this paper, but it occurs along the entire south coast of the continent, including all Tasmanian waters; it does not, however, usually extend in any strength very far north along the New South Wales coast. Its eastern limit of distribution is therefore close to one of those recognized for other species in connection with the above-mentioned system of areas. Without wishing to suggest, at this stage, that this system of geographical subdivision necessarily holds good for fish generally, some support for such a view could be drawn from a consideration of some of the important demersal species. For example, the tiger flathead (*Neoplatycephalus macrodon*) is more important between Port Jackson and the Furneaux Islands than to the north and south of these places, so that it is rather similar to the striped tuna, at least in the southern limit of its range; the snapper (*Pagrosomus auratus*) is virtually absent from Tasmanian waters, its place as the prime reef fish being taken there by the real trumpeter (*Latris lineata*), which is rare elsewhere in Australia (compare distribution of pilchard and sprat); the sand flathead of New South Wales (*Platycephalus caeruleopunctatus*) is not the same as that (*P. bassensis*) of Victoria, Tasmania and South Australia (cf. populations of pilchards); while the jackass fish or Tasmanian perch (*Dactylopagrus macropterus*) seems to have a range like that of the barracouta, extending from Western and South Australia through Victoria and Tasmania to New South Wales, but being generally unimportant beyond the southernmost part of the New South Wales coast. This whole question is very well worth the attention of ichthyologists, who might be able to indicate broad faunistic regions for these and other Australian waters in respect of fish populations, as has already been done for some invertebrate groups. Naturally any very rigid boundaries to such areas would not be expected, and this is not suggested for the pelagic fish already mentioned.

One feature, which seems to be common to all these surface fish occurrences in south-eastern Australian waters, is that the important shoaling (and other) pelagic species seem virtually confined to the relatively narrow band of water within the edge of the continental shelf. On the eastern seaboard this is little more than twenty miles wide at most. It was more or less expected that these species would be found most plentifully in these shallower waters, since, even with pelagic forms, this is usually the case in other seas; nevertheless

* These three species, and other pelagic fishes mentioned in this paper, also occur in southern Western Australia; but for at least some there are indications that the western populations are different.

it was a little surprising to find how marked this effect was in south-eastern Australia, even the outermost parts of the shelf waters themselves being almost as barren as those outside the edge. Speaking very broadly and taking the eastern seaboard as a whole, the writers believe that the Australian "salmon" characteristically occupy the most inshore position of any fishes discussed here, being but rarely seen beyond a mile of the shore. The same might be said of the sprat. Next come the horse-mackerel (and probably the kingfish and sea garfish), ranging from the shore to about three miles off. Pilchards and southern bluefin typically occupy a zone from about two to eight miles offshore, though both may come in very close to land; while striped tuna are most frequently found from about three to twelve miles off. The edge of the shelf mostly occurs at a depth of about 100 fathoms, except in Tasmania where it is about 70 fathoms. Since comparisons are so often made, in connection with pelagic fishery possibilities, between the waters of Australia and those of Pacific North America, it is interesting to note the position there regarding seaward extension of pelagic fish. According to F. N. Clark (1937), in central Californian waters little pilchard fishing is done (and few fish are thought to occur) outside the edge of the shelf, which is broadly identical with the 100-fathom line; but in southern Californian seas the catches (and apparently the fish) are concentrated over the outer slope of the shelf, between the 100- and 500-fathom lines. In terms of distance from the shore the position is nevertheless not very different from that obtaining here, since the shelf is mostly even narrower than in eastern Australia, so that in both the above cases the outermost limit of frequent occurrence of the shoals is of the order of ten miles offshore. However with tuna the position is very different in these American waters. The bluefin tuna fishing area of southern California extends to about fifty miles offshore (Whitehead 1931, pp. 18-19) although there are many large islands in this region and the actual distance from any land would probably be not so great in most cases; while the area for fishing yellowfin and striped tuna, between southern California and the equator, extends typically to between five hundred and a thousand miles from land (Godsil 1938, p. 8).*

Another general topic which arises from a study of the foregoing occurrence data, and which has an important bearing upon commercial fishing prospects, is that concerning natural fluctuations in supply of fish from year to year. Since this subject has hitherto received little attention in Australia fisheries literature, the following general discussion is appropriate.

Natural fluctuations in fish supply may be classified in the following manner:

(1) *Fluctuations in Abundance.*—In these cases there is an actual change in the numerical strength of the whole fish population concerned.† This may be caused by (*a*) or (*b*):

* Information recently received on the Japanese fisheries indicates that the main fishery for large tunas, swordfish, and pelagic sharks is more than 800 miles eastward from the coast of Honshu.

† There may occasionally be fluctuations in the *weight* of the population that are simply due to changes in growth-rate and not to differences in the number of fish present; in many cases, however, it is known that such growth-rate variations are actually consequent upon changes in numbers, for which they tend to compensate.

(*a*) Effects of widely differing mortality upon the very young stages (larvae, postlarvae, probably also eggs) in different years, giving rise to numerically rich, medium, and poor broods which result in good, medium, and bad years of abundance of the commercially fished stock after an interval corresponding with the age of the fish when it ordinarily reaches its greatest degree of importance. These differing mortalities and survivals are occasioned by variations in supply of suitable food, physicochemical effects of temperature and the like, to which the young fish may be sensitive or which may control food supply, and other phenomena which cause differences in the suitability of the aquatic environment for the young stages from year to year at the time of production of the spawn (including drift effects which may carry the young stages into a favourable or unfavourable environment; also, probably, predators and competitors).

(*b*) Effects of widely differing mortality upon the adult fish in different years, causing widespread sudden deaths (or, as the theoretical alternative, widespread temporary relief from the ordinary causes of natural death). These would also be caused by changes in the environment, of a generally similar nature to those just mentioned, but including artificial ones (e.g. pollution) and also the effects of parasites.

(2) *Fluctuations in Availability.*—In these cases there is a change in the abundance of that part of the population available for fishing, although the numerical strength of the total stock may be unaltered. These may occur as either (*a*) or (*b*):

(*a*) Migratory effects, wherein the fish stock may be scarcer than usual in a locality where the fishery normally operates, but in greater strength elsewhere; or more plentiful than usual in a fishing locality, but in fewer numbers elsewhere. In its simplest form an effect of this kind is merely a geographical re-distribution, in the horizontal plane, of a population of fish of "normal" abundance, but such phenomena could also be combined with effects such as either 1(*a*) or (*b*) above. They are also due to physicochemical or biological changes in the environment to which the fish are sensitive, or climatic changes facilitating or hindering migrations in special directions.

(*b*) More specialized effects wherein the fish stock may be present in a locality in its "normal" numerical strength, but in such a way as to be less or more available than usual to the type of fishing gear normally used for the capture of the species. This sort of effect would often amount to a redistribution of the stock in the vertical plane (see below), as compared with the case considered just previously. Probably the causes would again be found to reside in differences of the environment.

Fluctuations of the type of 1(*a*) above have attracted the most attention in fisheries biology, following the work of Hjort (1914) who first fully advanced this type of explanation for changes in abundance. Many important instances of this effect have been independently demonstrated since and there is no doubt that it has very general application for fish stocks, and is the major cause of changes in actual overall population abundance. The possibility of prediction of such changes is greater than for those of the other types, because of the time interval between the establishment of abundance of a brood and its

appearance in the commercial fishery; this permits the sampling of the juvenile fish with special gear, and comparison with the abundance of earlier broods whose subsequent history is known.

Changes of type 1(*b*) do not seem very important in respect of marine fisheries, although some cases are known, and the difficulty of obtaining positive evidence of large-scale adult mortality at sea, save in extreme cases, should be borne in mind. As one would expect, there are more instances from freshwater and other more circumscribed environments, where the possibilities of escape from a deleterious factor are apt to be less than at sea. Similarly, sessile organisms like shellfish would probably be more often affected than fish, and sluggish demersal types of fish more than the more mobile pelagic kinds. One could think of these effects as extreme instances of the phenomena of type 2(*a*), in which there was no (or only a very limited) possibility of migration out of an unfavourable zone.

Cases of the type 2(*a*) above are very important and have attracted much attention, but less is known of them than of those of type 1(*a*). Prior to Hjort's work on the juvenile survival effect practically all changes in fish supply were considered to be of this type, and most fishermen still assume this at the present time, i.e. " the fish are somewhere else ", not " the fish are altogether fewer ". This is probably because most of the minor fluctuations in supply, such as a temporary and apparently fortuitous preference of a swarm of fish for one part of a small bay or estuary as opposed to another, are probably always of this type, and it is this sort of change which most fishermen are able to study most closely. However, there is no doubt that major annual fluctuations of this type are quite common also, and may result in unusually good or bad harvests for the catchers, especially where the range of the fishery is limited.

Fluctuations such as type 2(*b*) are probably of less importance and receive little attention. They would include such cases as those in which a species usually fished at the surface was less available there than usual, being deeper down, as well as cases (if there are such which would substantially affect the output of a whole season) in which fish sought by hooking " wouldn't bite ". Changes of this sort over short periods (i.e. of the order of days or weeks) are of course extremely common and much more varied (e.g. when demersal fish temporarily ascend to the middle waters to feed, and so avoid the trawl).

Many fluctuations of types 1(*a*) and 2(*a*) are apparently of a short-term kind, i.e. involving one, two or three years only, but there is evidence of the occurrence of long-term fluctuations of both these kinds.

In the foregoing account reference was made to fluctuations in abundance or availability of various species, principally pilchard, " salmon ", horse-mackerel, and sprat. Referring to the previous classification of fluctuations, those of the New South Wales coast pilchard have been shown to be of type 1(*a*), i.e. true abundance variations of the common juvenile survival type. On the other hand, those of the " salmon " shoals at Narooma and elsewhere seem to be of type 2(*a*), involving a shift of occurrence from the inlets to the outside beaches. Again, scarcity of horse-mackerel shoals in south-eastern Tasmania

in the 1946 season was mainly an effect of type 2(*b*), i.e. a change in level of occurrence in the vertical plane.* The nature of the sprat fluctuations is not understood.

It is thus clear that the abundance indices in respect of shoal occurrences, and variations in these, do not all correctly indicate the position in respect of overall abundance of fish in the population. For the New South Wales south coast pilchard the total evidence is so consistent and so well in accord with biological findings, that one can confidently accept the shoals abundance index as one of true abundance on an overall seasonal basis. However for Tasmanian horse-mackerel, considering the events of the 1946 season, one would have to conclude that the same would definitely not be true for certain seasons, and might not be true at all. Similarly for sprat, lacking as we do evidence as to the real nature of the variations observed in the shoals abundance index, it would be necessary to admit the possibility that these changes did not reflect fluctuations in real abundance. All that is definitely measured by the quantitative data presented for these two species, therefore, is the actual occurrence of surface shoals, which is of course the most important information that would be required by anyone proposing to fish them by surface net, the most favoured method in developmental work upon them to date.† However, the evidence should be taken with reserve, as an indication of likely annual variations of numbers of fish as well as of the extent of the optimum season of their occurrence, by anyone who desired to fish for these species with drift nets, for example.

Fluctuations in abundance or availability have naturally a most important bearing on the success or failure of fishing operations, and this factor may become critical at times when the fishery is at the earliest developmental stage. An established fishery can, for example, in some manner survive the most disastrous periods of scarcity, even when these extend over more than one season; but when the work is only at the initial testing stage, and most other factors are in the balance also (suitability of boat and gear, availability of market and capital, enthusiasm of the fishermen, etc.), an adverse fluctuation can have the most depressing effect upon the whole enterprise. Such cases have more than once caused embarrassment to the Organization's officers and their collaborators in developmental work upon pelagic fish.

On the other hand there are the compensating " good years ", and obviously those responsible for the developmental effort with pelagic fish will have a much better chance of achieving success if they encounter one of these when commencing their fishing tests. Such an enterprise would have a good start, and might well survive subsequent adverse seasons. One case in which something of this nature apparently happened, and which is also interesting in that the type of information available is particularly comparable with some of the data in this paper, refers to the pilchard purse-seine fishery of the Canadian Pacific coast. According to Hart (1943, p. 55) this began in 1925, which was one of the three years in the history of the fishery to date in which the fishing season lasted longer than usual (the others were 1938 and 1941); but on the other

* See also separate paper, under this cover, by Keith Sheard.

† This is especially true of the data on " fishable " shoals.

hand there were also three years, 1933, 1937, and 1939, "in which no substantial schools of pilchard were observed in waters off the Canadian coast". Even a well-established fishery could benefit from a system of prediction of fluctuations, on which the operatives could base their outlay of expense etc. for different years, and this is the justification of much of the work that is being carried out on the nature and causes of such changes. Something on these lines could probably be done immediately for the New South Wales pilchard, if warranted by the emergence of a significant fishery.

With respect to quantitative data on surface shoals, it was stated that these are of value in indicating the general levels of abundance or their range of fluctuation as found in the various waters in different seasons by vessels seeking shoals to fish. However, it will probably be found, if and when any pelagic fishery becomes established and develops, that vessels will encounter shoals rather more often. Firstly, with increasing experience, their crews will undoubtedly discover that certain localities particularly favour the occurrence of the species concerned, and they will tend to spend more time there and thus find shoals at a somewhat higher level of abundance. Something along these lines has already been shown for shoals of spring pilchards in the Jervis Bay area, as compared with the New South Wales south coast as a whole. Secondly, as the number of vessels operating in any such fishery increases, there is bound to be voluntary or involuntary cooperation between them in the search for fish, so that the efficiency of each unit will be higher than it would have been alone. As is well known to those who have observed commercial fishing operations at sea, the more vessels there are in an area the more certain it is that some of them will find the fish in plenty, and be quickly joined by the rest, whether the latter's presence is desirable or not. Thirdly, the fishery might enlist the aid of scouting aircraft to locate fish shoals, and since aerial reconnaissance has been shown to have quite considerable possibilities in Australian waters, the efficiency of the boats would be significantly increased. This form of assistance would probably vary in effectiveness for different species.

A final point refers to the account of changes in abundance of the New South Wales pilchard. As pointed out above, the available occurrence data presented a rather involved picture in the early stages of the work, and this remained the position until the completion of an age-study (involving scale-reading etc.), after which all the apparent anomalies were explained and the clear pattern of Figure 2 emerged. This example seems to provide some justification for carrying out at times even moderately complex pieces of biological research concurrently with the survey and technological work upon an unfished species, a procedure whose value has at times been questioned by various people, including some of the research personnel themselves, during the current investigations by the Organization.

(*b*) *Remarks on Prospects for Commercial Exploitation*

(1) *Tunas.*—In this last part of the study some remarks are made regarding the methods most likely to prove suitable for capture of the various species. This is done bearing in mind what has already been shown here and elsewhere regarding the occurrences and general commercial utility of these species. Because of the tentative character of some of the conclusions, the remarks will

be brief. Some fuller statements on certain aspects of the matter have appeared elsewhere. As regards catching methods for the tunas, observations have been made by Thompson (1943, pp. 284-285), Fowler and Serventy (1944, pp. 2-3) and especially by Flett (1944). The general belief is that the live-bait method offers the best prospects, of which there is more discussion below. The Australian species are prime canning fish (see Wood 1940, p. 40, and 1941, p. 47; Serventy 1941*a*, pp. 32, 40, 41, 43; and Fowler and Serventy 1944, pp. 1-2).

(2) *Pilchards* (*and Anchovies*).—In past investigations the interest in these species was centred on their use as live-bait for tuna fishing. It was shown by Flett (1944) that both kinds could be held alive in bait tanks aboard ship, and by using them good quantities of tuna (southern bluefin and striped) could, in the season, be taken on pole gear as in the Californian fishery. From what has already been said about the seasons of maximum occurrence of these forms on the one hand and the tunas on the other in different areas, it appears that there are reasonable prospects for their use in this manner. For instance, live-bait of small pilchards from the spring and summer runs on the south coast of New South Wales (and probably on the north coast also, see p. 25) could be applied to the two tunas which appear there at the same time; the general season of occurrence of anchovies and pilchards at Port Phillip Bay includes most of the period at which striped tuna are usually in optimum abundance in north-east Tasmania, and there is no reason why these fish could not be transported there; and there is also a very similar season for both pilchards and southern bluefin in South Australian waters. Often the matter would not be so simple owing to fluctuations in bait and tuna species, but, where the former are concerned, there are several different stocks over the south-eastern area as a whole which fluctuate differently, and so a bait vessel capable of covering large areas would rarely fail to find some fish.

The only real problem is the actual mechanics of capture of bait fish regularly and in sufficient quantity, which is still a somewhat open question. Gill-nets are not suitable. Perhaps the Philippines method could be followed: the bait is caught by beach seines or similar inshore gear and transferred to floating pens nearby, where the tuna boats come to obtain their supplies (Domontay 1940). For this, the fish must be plentiful in inshore places which are shallow enough for such fishing, well sheltered for penning, and reasonably accessible to the tuna clippers. There are few places where these requirements are met. One such place might be Port Phillip Bay, where single catches of several tons each of anchovies and pilchards have been made by beach seine. There should be no great difficulty penning, as an experiment in Tasmania has shown that anchovies can be held alive for at least five months (Fowler 1942). Beyond this, the question involves the possible employment of large surface seines of the purse-seine, ring-net or lampara type, which make very big catches regularly in some overseas fisheries. Some discussion on preliminary work of this type has already been published (*see* Blackburn 1941, pp. 45-47, 96, 117-119; and Thompson 1943, pp. 283-284), and a little more can be said now in view of subsequent experience, but the matter still requires further attention. The position as summarized below refers mainly to pilchards, since anchovies do not typically occur in conspicuous surface shoals.

(i) The opportunities for using large purse-seines (i.e. about 200 x 20 fathoms or more) in the offshore waters will probably be somewhat limited, at least on the eastern Australian coast, because of weather conditions, "wildness" of shoals (at least the daytime ones which are on the whole the more conspicuous, see pp. 20, 28), and the depth of water (*see* Blackburn 1943, p. 269). However, payable operations might still result if the individual catches were large. The matter warrants more attention than it has yet received from skilled fishermen. In South Australia, where there is more sheltered water than in New South Wales, some of the above difficulties should be less evident. There are references to purse-seine design and operation in papers by Whitehead (1931) and Croker (1933, pp. 72-73).

(ii) The lampara net has had fair use in New South Wales and South Australian waters, with only middling results. The largest catch, 2 tons only (by the *Warreen*) was made at night. Most of the *Warreen's* daytime hauls yielded nothing. All her successful hauls were made in Jervis Bay (pilchards) and Twofold Bay (anchovies) from February 1940 onwards. The private vessel *Corwa* got positive results more regularly, though the maximum was lower, in Coffin's Bay, South Australia, in March 1940 (pilchards). Some of these hauls were made by day and some by night. The advantage of this gear is its small size and ease in handling compared with the purse-seine. It can be used in shallower waters, so that work can be done in inlets which are sheltered from the weather. However, there is more risk of escapement, especially by daytime, and this net would probably be most useful on moonless nights. For details of the structure and use of lamparas, see Scofield (1929), Fry (1931), and Croker (1933, pp. 98-99; 1938, p. 16). Small but regular day lampara catches of pilchards have recently been made in Western Australia.

(iii) There should be possibilities for using specially constructed small shallow purse-seines or ring-nets in the bay waters, and some work of this kind has been attempted in New South Wales recently. The nets used were more or less of the "Monterey ring-net" type (*see* Fry, 1931, pp. 30-32, 44), about 120-160 x 14 fathoms and with wings of very unequal length. The catches made (pilchards) were all well within the range of those of the *Warreen* lampara, but they were made much more often, even though there was no night work.

(iv) In cases where shoals were not found in the ordinary way (i.e. by their luminescence) at night, the fish might be brought to the surface in fishable concentrations by attracting them to a light. This is the usual practice in the Mediterranean for lampara fishing, although it is not so much in vogue in California (*see* Russo 1939; *Pacific Fisherman* May 1941). This was well demonstrated recently for pilchards and anchovies in Port Phillip Bay. Catches up to six tons were taken.

(v) It therefore seems that the most likely kind of surface-seine fishery for these fish (mainly pilchards) would be one based on relatively small and shallow gear, such as lampara, small purse-seine, or ring-net, to be used mainly at night in some of the more sheltered waters. With experience of this kind as a background, fishermen would probably have better prospects than otherwise

of successfully attacking the outside shoals. A few localities which seem to be particularly well suited for such operations are Jervis, Twofold, Port Phillip and Coffin's Bays.

It might be emphasized that a great deal of tuna fishing could probably be done with a very moderate amount of bait. This is indicated by the following calculation based on information published by Godsil (1938) regarding the California fishery, although the final result should not be taken to indicate anything more than an order of magnitude of the bait and tuna catch ratio. It appears (p. 9) that the fish capacity of a large tuna vessel ranges from 150 to 350 tons, so that 250 tons should be a fair mean figure. The capacity of these vessels for bait is generally between 1000 and 1500 "scoops," a scoop weighs from 8 to 10 lb. (p. 22), and so the mean bait capacity of a large boat can be stated approximately: 1250 x 9 = 11,250 lb. Godsil also says (p. 23) that the amount of bait required to load a vessel with tuna may vary from a fraction of a load of bait to two, three, or more loads, so that one might reasonably assume two loads to be a safe average figure. That is, to fill a large vessel with tuna, some 22,500 lb., or 11¼ U.S. tons of bait would on an average be required. Hence it appears that the mean ratio of bait used to tuna caught, is in the region of 1/20, as obviously some figure of this order is indicated. If a similar ratio applied here, it appears, for example, that some 15 million lb. of tuna (about 6700 tons in our measure), equal to about 20 per cent. of all Australian production of fish proper at the present time, could be caught with about 0·75 million lb. (about 335 tons) of bait. This does not seem an impossible task for a fleet of say 10 or 12 boats, for which the total tuna tonnage indicated would provide an extremely profitable return.

In connection with live-bait tuna fishing potentialities in Australia, attention may be directed to the appearance of "baby" tuna clippers in the Californian fleet, about 65 to 70 feet in length (*see Pacific Fisherman* March and May 1945). Some information upon bait tank construction is also available (*Pacific Fisherman*, April 1945).

All the sources and methods suggested above for obtaining these fish for bait would be applicable for procuring fish for canning, but there should also be good possibilities for drift-netting, in respect of which weather is not such an important consideration. This method might be used for pilchards at least. This would apply particularly to the offshore pilchard shoals which range along the New South Wales and south Queensland coasts between April and September, and fish might also be obtained deeper down at other seasons. A few experimental sets with very small nets have given hopeful results. Such nets are very productive in some overseas fisheries for pilchards and other clupeoid fishes. The appropriate mesh-sizes (at least for New South Wales fish) would be 1¼ and 1½ inches.

There is already a small demand for Port Phillip Bay anchovies for processing (at present for fish paste), and catches are made by beach seines and hoop nets lowered from the piers. Especially in winter, these fish are extremely plentiful in shallow waters suitable for beach-seining.

The question of pilchards as a source of oil has received attention previously (Blackburn 1941, pp. 44-45, 96). As mentioned therein, the only Australian pilchards that have been found to contain oil in payable quantities are those off the New South Wales north coast (especially off Port Stephens) in January, but these did not seem to be very common in the surface waters (Blackburn 1941, pp. 27, 39, 97-98). From the data of Table 4, the position regarding the abundance of these particular shoals appears rather better than this, but it still seems that there is little scope for an oil-reduction industry of any magnitude based on pilchards. Even if a further search revealed these oily pilchards to be present to the same extent over a longer season than this one month, and even if they were found on the south coast too (as noted previously, a few of the shoals found in the warmer months there are probably of this type), the season would still be short. Furthermore, there would seem to be no substantial prospect for regular catching by surface-seining methods in these offshore waters on the huge scale that would be required, because of weather conditions which are not very good in summer, and other reasons. Oily fish may also yet be found in the off-season (in this case winter) in Victorian and South Australian waters, but there would probably be the same difficulties of supply. The fact is that in south-eastern Australian seas all the main surface (i.e. most readily available) occurrences of adult pilchards are spawning runs, in which the fish are at their poorest condition and contain little oil; the oily fish compose the between-season occurrences. The young spring and summer fish of New South Wales waters are poor in oil, probably because of their size (Blackburn 1941, p. 119). All these non-oily pilchards would be suitable for white fish meal manufacture.

(3) *Horse-mackerel.*—In south-eastern Tasmania, where this species seems to occur in the greatest concentrations, it has attracted considerable interest in recent years as a possible source of good quality fish for canning and curing. Because of this, and because the shoals and the geographic and climatic conditions under which they occur gave promise of favourable surface-seine fishing operations, they have received more attention on the catching side than any other unexploited Australian pelagic fish. No details are given here as two reports have been published (Blackburn 1943; Blackburn and Olsen 1947). Briefly there were tests made, from 1941 onwards, by lampara, ring-net, and purse-seines of several kinds. Some small successes were obtained by 1943, but further experimentation was necessary, and it was not until 1947 that really promising results were obtained. These took the form of two catches of 15 to 16 tons each within one week, with a purse-seine about 200 x 20 fathoms (2-inch mesh), the first commercial-sized hauls of any surface seine in Australia. More recently (October and November 1947) the same crew captured from 12 to 20 tons of these fish in each of four hauls off the New South Wales south coast. This followed the lengthening of the above-mentioned net to 245 fathoms. Further catches were made in July 1948, in the same region. As shown previously in this report, shoals suitable for such fishing are liable to be found on one in every five and a half days on average, over a five-months' season in south-eastern Tasmania, and this applies in almost every year. The general outlook for developing a purse-seine fishery for this species there is thus very good.

(4) *Sprats.*—The question of fishing methods for this species, in the rather restricted Tasmanian waters where it occurs at all plentifully, has received considerable attention concurrently with the work on the horse-mackerel in the same general sector. This effort has recently been brought to a definite stage (see Blackburn and Olsen 1947). It can be said here that operations commenced in 1940 and have involved a variety of large floating seines, but mostly lamparas, with which catches of up to 2½ tons (but mostly under 1 ton) have been made with some regularity. Because the effective range of the species is not very wide and the order of occurrence of good shoals not very high (see Section III (7)) it is considered that the prospects for commercial exploitation are somewhat limited, and operations are to be visualized merely as adjuncts to existing fisheries in the same area. Since these mostly employ small boats with crews of no more than two or three men, the appropriate gear seems to be a small lampara, with short wings that can be hauled in very quickly before the fish escape through them. In 1947 a net of this type brought in approximately a ton of fish on each of the three days on which numerous shoals were available, with three and sometimes two men working, although about three hauls a day had to be made to get this result. This was regarded as satisfactory by those concerned and it seems likely that a small dependent fishery will eventually develop along these lines. The fish are suitable for canning, and have an excellent flavor that renders them particularly suitable for fish paste. The oil content in the main season of occurrence is moderate on the whole (it varies with the size of fish), but of no commercial significance in view of the anticipated small output. A random sample had 9.1 per cent. of oil by weight, equivalent to a yield of 22.2 Imperial gallons per long ton, or 23.6 American gallons per short ton. According to Clark (1937, p. 132) the minimum yield in the Californian pilchard industry is 23 (American) gallons per (short) ton. The fish scale very easily and are thus unsuitable for live bait (Flett 1944, p. 61).

(5) *Australian "Salmon".*—During the last thirty years the Australian "salmon" appears to have played the role of stabilizer in the fresh fish supply, particularly in Victoria. From the statistics available, it seems fairly clear that the sales of "salmon" in the central markets have increased as those of other species (except barracouta) decreased, and *vice versa*. Admittedly, "bad" years have been experienced by the "salmon" fishermen, but generally speaking a sufficient quantity of this species has been available to make up largely for any failure in catches of the better classes of fresh (table) fish.

The development of the fish canning industry in New South Wales and Tasmania resulted in a marked increase in production of Australian "salmon" (from about 660 tons in 1937 to 2,665 tons in 1940 for the entire south-eastern Australian catch) but efforts to maintain this augmented catch were annulled by the failure of the fish to enter the inlets (see pp. 32, 34), particularly those of the Wonboyn and Wagonga Rivers, which provided the bulk of the increase. Since 1940, almost the whole catch has been made by fishermen operating on ocean beaches or in the larger bays, and under these conditions the fish are not nearly as vulnerable as when they entered the inlets.

Any great expansion of the fishery for Australian "salmon" depends upon the development of deeper types of nets which will permit the fishermen to attack those shoals which travel along the coast too far from the beaches to be captured by the present surf haul seines. A large proportion of the observed

" salmon " shoals falls within this category. The Organization instituted work along these lines in 1942, but wartime requisitioning of suitable vessels compelled abandonment of the project before any tests could be undertaken.

(6) *Other Species.*—Of the other species mentioned in the foregoing sections those which appear to offer the greatest opportunities for further exploitation are the kingfish (*Seriola grandis*), sea garfish and true mackerel. The development of a heightened fishery for these species depends upon the utilization of pelagic nets such as the purse-seine, ring-net or lampara, adapted to suit Australian conditions.

V. Acknowledgments

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The survey and fishing work done in collaboration with the Organization by the Tasmanian Department of Agriculture has been of very great value, and it is desired to thank Mr. H. C. Smith, Secretary for Agriculture, Messrs. L. A. St. Leger and R. H. Scott, present and past Secretaries of the Fisheries Division, Captain H. Johnston, and Messrs W. Warn and A. Burnett, of the State Fisheries vessel *Liawenee,* and most particularly Mr. T. J. Challenger, Inspector of Fisheries. The various inspectors of the New South Wales Fisheries Department have provided records to which reference has been made, and for Victoria Mr. A. D. Butcher, Director of Fisheries and Game, has been of considerable assistance in accumulating data on clupeoid fish.

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Mr. E. A. Cornish, Officer-in-Charge of the Section of Mathematical Statistics, C.S.I.R.O., checked the parts of the paper dealing with the chi-square test.

Sections of this paper that deal with the pilchard, anchovy, sprat, and horse-mackerel (except for New South Wales in the last case) were written by Blackburn, and the sections on " salmon," and the New South Wales inspectors' data generally, by Tubb. The general portions of the discussion section, and the continuity of the paper are mainly the work of Blackburn, but the statements made represent the views of both authors.

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APPENDIX 1

On Corrections in Chi-Square Tests in the text, involving Small Expected Numbers

In 10 of the 13 tables in the text in which calculations of χ^2 are made, expected numbers of less than 5 occur; this might be regarded as necessitating, as a check on significance or otherwise, the recomputation of χ^2 by the method of grouping the data mentioned by Snedecor (1940, pp. 168-69, 174): the three Tables 12, 13, and 29 are not affected.

Of these 10 requiring a check, it was impossible to achieve any suitable grouping in two, Tables 4 and 34, and no proper check could be made for them; and in two others, Tables 27 and 28, no attempts at recomputation were made, since, as explained in the text, the information conveyed by these tables is in any case regarded as less reliable than that conveyed by Tables 29 and 30. In the other six cases, however, Tables 3, 8, 9, 10, 30, and 33, these recomputations were carried out, but in no case was the general position of signficance or non-significance of χ^2 for the 5 per cent. point thereby rendered different. This was so for Table 33, the most questionable case, where the original value of χ^2 was a little below the 5 per cent. point; by grouping the data into two larger "samples," the 1940, 1941, and 1942 information in one and the 1943 and 1944 information in the other, a value of χ^2 was obtained which was also a little below the 5 per cent. point, well above the 10 per cent. point, confirming this series as a borderline case from the point of view of homogeneity.

One could safely assume from these results that the general position as revealed by the original computations for Tables 4 and 34 is also quite reliable in each case. In any event, according to Snedecor (p. 169), it is now thought that errors introduced by small expected numbers are not serious on the whole.

FACTORS IN THE BEHAVIOUR OF PELAGIC FISH SHOALS IN SOUTH AUSTRALIA AND NEW SOUTH WALES

By Keith Sheard

During the course of an extensive examination of marine invertebrates, both bottom living and freely swimming, and the contents of the stomachs of fish in South Australian and New South Wales waters, considerable attention was given to feeding and other movements of pelagic fish shoals.

Although the evidence will be presented and the results discussed in detail in a forthcoming bulletin*, some general statements and observations are not out of place in this paper.

Pelagic fish shoals are dependent for their food supply, as regards their animal food, upon the marine invertebrate population, either directly from time to time, or indirectly, through the medium of smaller fishes.

The marine invertebrates can be divided into four general classes:

(*a*) Those which spend their lives freely floating, with no bottom living or bottom seeking phase. Their greatest concentration is generally in the upper layers.

(*b*) Those which spend their adult lives freely swimming in the waters of the trawl zone†, but which tend to rise towards the surface at night. They apparently spawn in the upper layers and the larvae have their greatest concentration in the upper layers. A good example is the Euphausiid *Nyctiphanes australis,* the so-called "krill" of south-eastern Australian coastal waters.

(*c*) Those, whose adults always remain closely associated with the bottom, but whose larvae enter into the freely floating plankton. In this class are rock crabs, shrimps, hermit crabs, mantis shrimps, and many others. These contribute enormous swarms of larvae to the plankton, usually in irregular floods.

(*d*) Those which are permanently attached to the bottom and whose larvae remain closely associated with it.

Classes (*a*), (*b*), and (*c*) are those with the greatest influence on fish feeding movements, and the general behaviour of pelagic fish in any area appears to depend to a large extent on the proportion of those classes present at any one time.

The coastal waters of New South Wales and eastern Tasmania are characterized in the main by animals drawn from classes (*a*) and (*b*); their proportion to class (*c*) is about 60 per cent. to 40 per cent. During spring and early summer *Nyctiphanes* is generally abundant, particularly in the night rises. The production of larvae of class (*c*) appears to be fairly constant during the year except for occasional, very heavy, swarms of mantis shrimp (*Squillid*) larvae.

* Sheard, Keith (1948).—Plankton characteristics of the Cronulla Onshore Station, N.S.W. Commonw. Sci. Industr. Res. Org., Aust. Bull. No. 246.

† The region of water immediately above the bottom and within the vertical sweep of the otter trawl.

It is evident that the more even the production of larval forms and the higher the proportion of class (*a*) animals in the plankton, the greater will be the concentration of pelagic fish in the upper levels and, other things being equal, the more stable the schools. In waters where the plankton population consists of a very high percentage of permanent plankton during the feeding season, fishes such as the herring show these attributes to a high degree.

Under the Australian conditions studied, a considerable admixture of temporary plankton appears to be the rule.

This is most marked in the waters of South Australia and the west coast of Western Australia, where conditions are reversed and the proportion of temporary (class (*b*)) plankton can rise to 60 per cent. or higher. The stomach contents of various pelagic fishes (tunas, salmon, pilchards, sprats, mackerel) reflect this changeover. For instance, the fishes taken along the New South Wales coast contain, directly or indirectly, about 60 per cent. of animals of classes (*a*) and (*b*); those taken in South Australian and Western Australian waters show about 60 per cent. (higher in Western Australia) of class (*c*).

The behaviour of fish schools in relation to their food supply was observed in South Australian gulf waters (1938-44) when the southern bluefin tuna (*Thunnus maccoyii*) and its chief food there, the blue sprat (*Stolephorus robustus*), were studied with the assistance of members of the Big Game Anglers' Club of South Australia, particularly Messrs. E. Hanka, L. Hannan, and J. Oswald.

To simplify an involved picture, it was found that, during the years 1938-40, the gulf waters in the summer season were populated with a high proportion of organisms which behaved as a more or less permanent plankton mass; elements of this included "krill" (*Nyctiphanes*), several species of amphipods (*Paradexamine moorhousei* and *P. frinsdorfi*) and the ghost prawn (*Lucifer*). This plankton tended to be concentrated in certain areas, for example, off Rapid Bay and Backstairs Passage in St. Vincent's Gulf; off the Althorpe Island, Thistle and associated Islands, and Cape Catastrophe in Spencer Gulf; and off Cape Borda (Kangaroo Island).

Although the blue sprat was the chief food of the tuna over this period, a few pilchards (*Sardinops neopilchardus*) and maray (*Etrumeus jacksoniensis*) were also taken. In addition, the tuna stomachs contained specimens of the plankton organisms mentioned earlier. These organisms were also the chief elements in the stomachs of smaller fish.

Over this period the schools of tuna were large, tended to hold together well, progressed fairly slowly as schools and were not very "wild." They were accompanied by large numbers of birds (terns and gannets), and spent much time on the surface.

During part of 1940 and from then on, the nature of the plankton changed. *Nyctiphanes* disappeared from the gulf waters and became scarce in the outer waters. The amphipods and ghost prawns became greatly reduced. In their place, occasional swarms and concentrations of class (*c*) plankton were evident.

No pilchard or maray were taken in the tuna stomachs, which contained blue sprats, and occasionally even snapping prawns and crabs, usually regarded as strictly bottom living.

While there were indications that the overall numbers of tuna in the areas in the season might not have been very much less than in earlier years, they apparently did not penetrate as far north in the gulfs.

Over this period, the schools were small, quickly moving, very "wild," spending little time on the surface. The birds spent much time in scouting and would follow submerged schools for considerable distances in a ludicrous semi-diving attitude. When the schools appeared at the surface, there would be a short flurry of activity, when the whole process would be repeated.

The stomach contents of the blue sprats from the tuna stomachs taken at this time generally included, in addition to the class (*c*) plankton, ostracods and other organisms characteristic of the general trawl zone. It is reasonable to assume that the blue sprats were obliged to find their food among the normal inhabitants of the trawl zone and from the swarms of larvae as they hatched from the egg-masses of the bottom living animals. The tuna sought the blue sprats at depth and only occasionally drove them to the surface. The only exception to this type of feeding behaviour was noted in Spencer Gulf at times when the tuna were feeding directly on spawning blue sprats in the upper levels of tide rips.

While feeding schools do not represent the only type of schooling, they are of sufficient importance to dictate fishing methods, particularly in coastal waters. Changes, both in time and place, certainly occur in the basic food organisms upon which the pelagic fishes depend in Australian coastal waters, and the continued study of the effects of these changes should be of value to the fisheries.

Explanation of Plates.

Plate 1

Fig. 1.—Typical pilchard shoal, north coast, New South Wales.

Fig. 2.—Close-up view of shoal of sprats, southern D'Entrecasteaux Channel, south-east Tasmania. The little splashes made by the fish are characteristic of the shoaling habit of pilchards also. The net in use is the lampara, being operated from M.V. *Warreen*.

Plate 2

Fig. 1.—Typical horse-mackerel shoal, south-eastern Tasmania.

Fig. 2.—Close-up view of horse-mackerel shoal, south-eastern Tasmania. Shoals of Australian "salmon" are very similar in appearance.

FIG. 1.

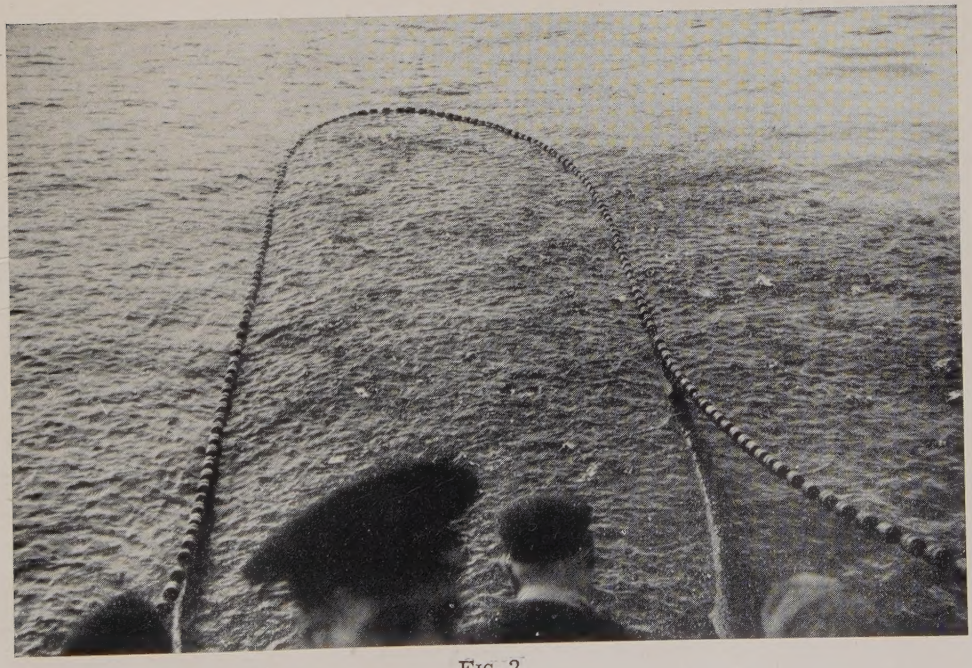

FIG. 2.

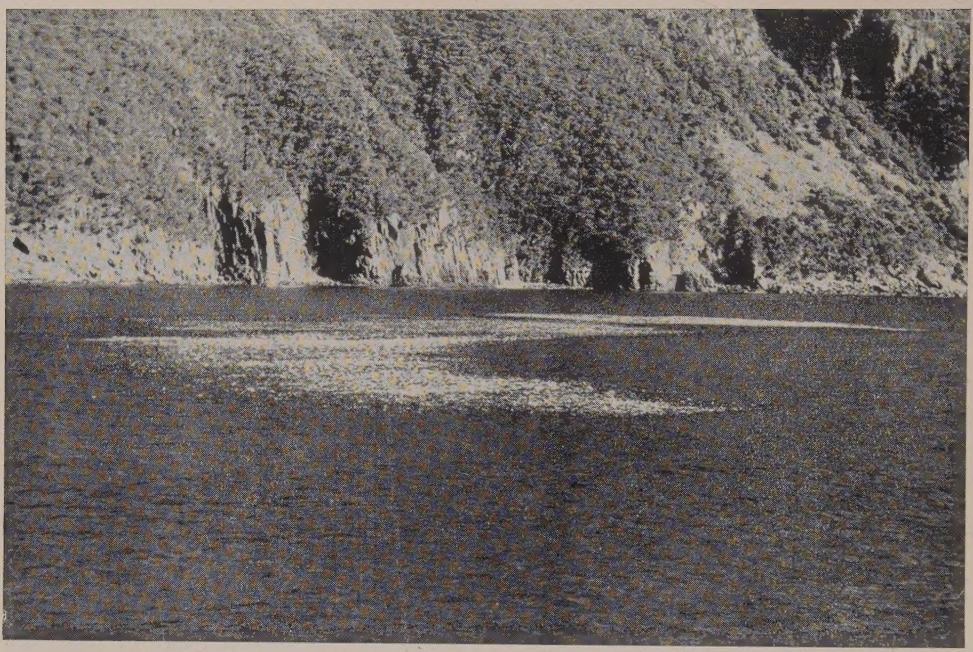

FIG. 1.

FIG. 2.

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